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LEARNERS' IDEAS ABOUT MEASUREMENTS.

a

RESEARCH REPORT

Submitted by

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In partial fulfilment of the requirements
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IN

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UNIVERSITY OF THE WITWATERSRAND

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ABSTRACT

This study investigated understanding of measurements by students in scientific activities that are experimentally based. The study focused on grade 12 high school learners in an urban South African School. The majority of these students were second language English speakers. Data were obtained through a written questionnaire given to students, to explore learners' ideas about data collection, data processing and data comparison, in particular the need to repeat measurements and the implication of the scatter associated with numerical and graphical data.

An alphanumeric coding scheme adapted from Lubben et al. (2000), was used as an analysis tool. This included categorising responses into point or set paradigms. The findings of this limited study maybe summed up as follows:
There is some consistency in reasoning across the experimental phases of data collection and data processing but it was noted that there is little use of set reasoning. It seems that students had specific difficulties in understanding the role and value of statistical tools in assessing confidence in measurement.

By and large the learners in this study did not appreciate the need for error analysis. The overall study suggests that though the correct procedures are followed students have little or no understanding of the factors taken into account during data analysis. The findings show that very few students are true set reasoners; 75% of the students chose to take an average because that is the way it was always done. Students' views may have been influenced by either exposure to 'cook book' laboratory sessions or by the context of the questionnaire which asks for three repeats. The study also shows that students had specific difficulty in understanding the role and value of statistical tools in assessing confidence in measurement (Mc Dermott & Redish, 1999).

In conclusion though analysis shows a large percentage of students appear to be point reasoners, they may appear at first sight to be set reasoners. The term average was used by students yet a recurring value was chosen. There is therefore a need to perform experiments in a meaningful context and move away from 'cook book' laboratories to appropriate non-traditional laboratory activities, so as to enhance higher order thinking.

DECLARATION

I declare that this research is being submitted for the degree of Master of Science in Science Education in the Faculty of Science of the University of the Witwatersrand, Johannesburg. It has not been submitted to any other university.

S.KHAN

September 2008.

DEDICATION

I would like to dedicate this to my supervisor Prof. Marissa Rollnick, without whom I would not have been able to succeed in completing this research report. I thank her for being so patient with me, and constantly supporting me in completing my studies.

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Table of Contents

ABSTRACT 2
DECLARATION 3
DEDICATION 4
ACKNOWLEDGEMENTS 5
Table of Contents 6
List of Figures 8
List of Tables 9
Chapter 1 - Background to the study 10
1.1 Introduction 10
1.2 The problem 11
1.3 Aim of the research 12
1.4 Motivation for research 12
1.5 Research questions 14
1.6 Organization of project report 14
Chapter 2 – Literature Review 15
2.1 Introduction 15
2.2 Theoretical background 15
2.2.1 Research into “Children’s Science” 15
2.2.2 The contrast between “meaningful” and “rote” learning (Novak, 2002) 16
2.2.3 A Constructivist approach in developing procedural knowledge. 17
2.2.3.1 Theoretical progress in the twentieth century 17
2.2.3.2 Constructivism foregrounds the role of learners’ prior knowledge 19
2.3 Literature review 22
2.3.1 Practical work 22
2.3.2 Procedural knowledge 25
2.3.3 Collecting data 29
Chapter 3 – Research Design 34
3.1 Introduction 34
3.2 Research approach 34
3.3 Research technique 35
3.3.1 Justification 35
3.3.2 Format of research instrument 36
3.3.3 Research sample 39
3.3.4 Pilot study 40
3.3.5 Administration of the test 40
3.3.6 Coding system 41
3.3.7 Validity and Reliability 42
3.3.8 Ethical considerations 44
3.3.9 Limitations of the study 44
Chapter 4 – Analysis of Results 46

4.1 Introduction 46
4.2. General observations about the data..... 47
4.3. Students' understanding of measurements..... 48
4.3.1 Results of data collection. 48
4.3.2 Results of data processing..... 53
4.3.3 Results of data comparison. 56
4.4. The use of a point and set paradigm of measurement. 60
4.4.1 Use of paradigm for data collection..... 61
4.4.2 Use of paradigm for data processing 64
4.4.3 Use of paradigm for data comparison..... 67
4.5 Conclusion 69
Chapter 5 – Conclusions and Recommendations..... 70
5.1 Introduction 70
5.2 Answers to research questions..... 72
5.3 Reflection on the Study 77
5.4 General recommendations 79
5. 5 Research recommendations 80
REFERENCES 81
APPENDIX 1 Sample of lab. work 87
APPENDIX 2 Questionnaire 89
APPENDIX 3 Alphanumeric coding scheme 99
APPENDIX 4 Analysis of Results..... 113
APPENDIX 5 Research request form…….....118
APPENDIX 6 Sample of student response……...127

List of Figures

Figure 2.3.2.1. Components of procedural knowledge. Obtained from Millar, *et al*. (1994)---26
Figure 3.3.2.1. Context of the questionnaire ..... ….. ……..37
Figure 4.3.1 Histogram to show analysis of Data collection. . 53
Figure5.2.1. The goal of instruction in relation to point and set paradigm..... 76

List of Tables

Table 2.3.2.1. Model of progression of ideas concerning experimental data. Adapted from Lubben & Millar (1996) in Campbell *et.al* (2005).....27

Table 3.3.2.1. Summary of the probes .....**Error! Bookmark not defined.**39
Table 4.3.1.1. Sample of coding method 50
Table 4.3.1.2. Analysis of responses to RD, RDA and RT probes into six main ideas... 51
Table 4.3.1.3. Summary of responses to probes RD, RDA and RT. 51
Table 4.3.2.1. Example of coding of probe 5..... 54
Table 4.3.2.2. Summary of responses to the AN probe **Error! Bookmark not defined.**55
Table 4.3.3.1. Example of coding responses. .....**Error! Bookmark not defined.**57
Table 4.3.3.2 Summary of responses to the SMDS probe.....57
Table 4.3.3.3 Example of coding responses for probe DMSS.....58
Table 4.3.3.4 Summary of responses to DMSS probe.....59
Table 4.4.1.1 Frequencies of Point and Set Data collectors.....63
Table 4.4.2.1 Sample of UR probe analysis.....65
Table 4.4.2.2 Frequencies of Point and Set Data processing.....67
Table 4.4.3.1 use of paradigm in data comparison.....68
Table 5.2.1: Actions and reasoning associated with point and set paradigms. (Adapted from Campbell *et al*.2005).....75

Chapter 1 - Background to the study

1.1 Introduction

The proposed study is an investigation into the thinking and action of learners' performance with regard to experimental investigations in the laboratory. It also aims to understand learners' reasoning about the reliability of experimental data.

In high school teaching, learning about measurements has a lower priority than content knowledge. Learners are told to repeat readings, but it is seldom explained WHY this should be done, and what factors should be considered when taking measurements. The problem is twofold: teachers may not see the need to explain, and students may not question. Hence different conceptions are held by science students at various levels of their study, due to a lack of understanding of the reasons for the procedures to follow. Most learners think that measurements need to be repeated because that is what they have been told by the teacher. This trend is re-enforced by local textbooks such as Physical Science 2000 Standard 10 (Heyns, Devilliars, Gibbon, Jordaan, Naidoo & Fowler 1999), which provides a step-by-step procedure, without the necessary explanation of the significance of the procedures. Similarly, departmentally mandated portfolio activities in some schools are also recipe-like (see appendix 1). The ultimate assessment of the scientific knowledge of learners is also not fully addressed in the National exam paper for the old grade 12 curriculum, which ended in 2007, where little or no emphasis is placed on practical work/measurements though the new curriculum emphasizes scientific inquiry and problem solving skills in learning outcome 1(DOE,2007). In the old curriculum, much time was spent on declarative knowledge *i.e.* knowledge associated with theoretical aspects of science, and little emphasis given on procedural knowledge. The purpose of this study is to explore students' ideas about data collection, data comparison and data processing with the need to repeat measurements.

1.2 The problem

Some students have difficulty in handling and interpreting a set of experimental measurements. As a practising secondary school science teacher, I have observed that students lack the skill of handling laboratory equipment. It was also observed that some students pay little or no attention to data handling. Data handling includes the construction and use of tables and graphs, as well as recognition of patterns in data. Anomalies, variables, precision and accuracy in carrying out an experiment are issues with which learners grapple with. However, this report deals with only one of the aspects of data handling, which is dealing with anomalies.

One should analyze the measurements looking for patterns or relationships that eventually lead to new ideas about the world in which one lives. Measurements form a large component of practical work, which affect every aspect of our daily lives.

Practical work represents a significantly large element of school science in some countries, in particular in the UK, although its quality and clarity of purpose has been open to some criticism (Hodson, 1990). As a teacher, I noted that most primary school learners enjoy practical activities, and that they look forward to the laboratory environment and the excitement and danger that secondary school practical work might offer. However, a number of students dislike practical work (Head, 1982). Practical work could be considered to be made up of three elements: nature of evidence, handling data and manipulating apparatus (Millar, Lubben, Gott and Duggan, 1994). The skill of manipulating the apparatus is improved by being exposed to laboratory tools.

Practical work has been used in high schools and tertiary institutions for various reasons and purposes. In general there are two sorts of rationale for practical work which are:

- to facilitate the learning and understanding of science concepts, and
- to develop competence in skills and procedures of scientific inquiry (Millar, 1991).

Hodson (1996) highlights three types of learning through practical work:

1. Conceptual understanding – declarative knowledge reinforced through practical work.
2. Procedural knowledge – ways and means of handling and interpreting data.

3. Manipulative skills – handling of scientific equipment.

Procedural knowledge is the ability to actually carry out an investigation, and then take action on the results obtained from the investigation. Black (1993) and Osborne (1996) stress, that procedural knowledge must be implemented through practical work so as to reinforce declarative knowledge. Allie, Buffler, Kaunda, Campbell and Lubben (1998) point out that at that time the procedural understanding of science was rarely studied, nor was it used as a starting point for teaching. This report is concerned with the nature of procedural knowledge in the area of measurements that high school learners exhibit during practical investigations. The findings do not suggest a framework for designing appropriate teaching strategies; however, further studies may explore the relationship between the teaching strategies used and learners' procedural knowledge.

1.3 Aim of the research

In line with the foregoing statement and background to the problem, the aim of this project is to investigate learners' reasoning about reliability of experimental data and determine learners' consistency in their reasoning.

1.4 Motivation for research

Practical work is a very important aspect of scientific literacy. At different levels of education, practical work may take different forms, such as inquiry, discovery or guided learning, but it is imperative that practical work consist of investigation, exercises and experiences (Woolnough, 1991) in order to study phenomena. In this way, practical work is done to enhance students' understanding of the theories of science and to develop the ability to do practical problem solving (Woolnough, 1991).

Practical work is defined as:

All those teaching and learning activities in science that involve students at some point in handling or observing the objects or materials they are studying (Millar et al., 2002).

This implies that practical work involves conceptual activity as well as practical activity.

Psillos & Niedderer (2002), discuss the effectiveness of labwork by firstly comparing the actual activities of students during labwork to the intended activities. This means that only the

effectiveness of labwork is determined, and secondly, effectiveness was determined by comparing the actual learning outcomes after labwork with aims and objectives set for a specific lab.

Brotherton and Preece (1996:66) divide process skills into two categories: basic and integrated skills.

- Basic skills involve observing, measuring, inferring, classifying, predicting, using numbers, using space/time relationships, recording and displaying data.
- Integrated skills involve interpreting data, controlling variables, defining operationally and formulating hypothesis.

Millar (1991) rejects Brotherton and Preece's (1996), definition of practical work as process skills. According to Millar (1991) practical work involves practical skills and that general cognitive processes cannot be taught by practical work: they can only be sharpened with the use of practical work in institutions of learning. As for practical skills and inquiry techniques, these can be taught to the learners (further discussed in chapter 2). However, much of the practical work being performed in various educational institutions does not meet the above criteria.

In the South African Education system, the National Curriculum document (DOE, 2007) requires some scientific investigations to be carried out as an open-ended task, where pupils can decide what apparatus to use and what observations or measurements to make, with the focus on scientific ways of working rather than obtaining results to support the teaching of science content. As a practicing high school science teacher, I have observed that generally students do not know why experiments need to be repeated and how to handle the data obtained. In most schools students simply follow instructions to carry out experiments. Learners can go through the steps without even thinking about what they are doing and why they are doing them. With experience in laboratory outcomes, some learners even change their results to suit their desired outcome (pre-ordained knowledge). According to Hodson (1990:33):

"..as conducted in many schools, if [practical work] is ill-conceived, confused and unproductive. It provides little of real educational value. For many children, what goes on in the laboratory contributes little to their learning of science or to their learning about science. Nor does it engage them in doing science in any meaningful sense. We need to ask, as a matter of some urgency, how this state of affairs has come about and, more importantly, what we can do to remedy the situation. At the root of the problem is the unthinking use of laboratory work."

Practical work must involve much more than a mindless following of directions if useful learning is to occur during laboratory sessions (White, 1991: 78). Hence, an understanding into learners' thinking processes during the collection of data may help teachers as well as curriculum developers to emphasize the need for greater focus on the process of practical work.

Another reason for selecting this topic for research is because a similar topic was done for my BSc (Hons), research project. The study was carried out using questionnaires designed by Lubben, F., Campbell, B., Buffler, A. & Allie, S (2000), however, at that time the grade 11 students were following the old science curriculum.

1.5 Research questions

The research questions relevant to this study are:

1. What are learners' views on the collection of experimental data?
2. What understanding do learners have about why readings should be repeated to collect a set of data?
3. What understanding do learners have about the factors that should be taken into account in processing and comparing data sets?

1.6 Organization of project report

In chapter 1, the aim of the research, motivation for the research and research questions are identified and discussed. The problem addressed by the study is also explained.

In chapter 2, the theoretical background and the literature review establish the context of the study. Some specific mention will be made of procedural understanding and how it fits in with the constructivist view of a learner. Previous research done in practical work will also be mentioned.

Chapter 3 outlines the research design, where the research approach, techniques, sample and instrument will be discussed. Other topics dealt with here are the analysis method, ethical considerations and limitations of the study.

In chapter 4, the findings are analysed and each of the eight probes that make up the research instrument are discussed in turn.

Chapter 5 draws conclusions and makes recommendations.

Chapter 2 – Literature Review

2.1 Introduction

This chapter contextualises the theoretical framework and reviews literature research done by various groups to explore learners' ideas and understanding of measurement.

2.2 Theoretical background

In this study students observe a demonstration, without actually performing an experiment and attempt to answer probes into their understanding of the demonstration. The probes are analyzed in light of the research into children's science (Gilbert, Osborne & Fensham, 1982), into the contrast between "meaningful" and "rote" learning (Novak, 2002) and into a constructivist approach to developing procedural knowledge.

2.2.1 Research into "Children's Science".

Since the study focuses on the understanding of procedural knowledge it is important to reflect on students' views of science. Gilbert et al. (1982:625-627) define "children's science" as the notions, beliefs and expectations which form conceptual structures that provide a sensible, coherent understanding of the world from the child's point of view. These authors highlight some distinguishing features of "children's science". These are:

1. Young learners tend to offer an account of formal science concepts using everyday language.
2. They often resort to self-centered and human-centered explanations for formal concepts treating phenomena as personal experiences.
3. To many young learners, "non-observables" (or that which cannot be seen or directly observed with the senses) do not exist.
4. Objects are assigned characteristics of humans and animals when learners speak of objects as having feelings, exercising their will, or performing purposeful actions.

Gilbert et al. (1982) argue that it is necessary for teachers to learn about children's science, for the reason that children's views are sufficiently strong and persistent that these will impact upon science teaching. Three aspects of getting to know children's sciences are thought to be important, namely:

- Teachers ought to know how to explore the status of their learners' views on topics to be taught and learned;
- Teachers ought to determine the content and nature of their learners' views;
- Teachers ought to consider the various ways in which children's science may, or may not, be modified by learning experiences.

The contention that Gilbert et al. (1982) make is that a teacher ought to listen to, be interested in, and value the views that children bring to science class. Teaching efforts that fail to take such views into account are almost guaranteed to fall short of achieving even the modest objective of making learners aware that there is an alternative viewpoint to theirs, namely that of the scientific community.

2.2.2 The contrast between "meaningful" and "rote" learning (Novak, 2002)

In analyzing the probes, this study looks further into the consistency of reasoning used by students during data collection, data comparison and data processing. Research by Lubben et al. (2001) suggests that some students apply rote learning in practical science. Drawing on the work of Ausubel, Novak (2002:549) distinguishes between rote learning and meaningful learning, stating that "meaningful learning involves substantive, non-arbitrary incorporation of concepts and propositions into cognitive structure". Meaningful learning, according to this view, requires a well-organized, relevant knowledge structure, as well as high commitment on the part of the learner to seek relationships between new and existing concepts and propositions. Meaningful learning takes place "where the learner chooses conscientiously to integrate new knowledge" with existing knowledge. In contrast, rote learning takes place when learners are forced to memorize information that has little relevance, and is poorly organized. Rote learners have little or no commitment to

integrate new ideas with existing relevant knowledge (Novak, 2002:552). Novak argues that all learning lies on a continuum between these two extremes.

Traditionally, teaching has provided learners with experiments that are described in detail (cook book instructions). Learners can go through the steps without thinking about what they are doing and why they are doing them. Practical work must involve much more than this mindless following of directions if useful learning is to occur during laboratory sessions (White, 1991: 78).

This study looks into students' reasoning to determine if students understand how to deal with a set of measurements or if they apply a routine method in their decision making.

2.2.3 A Constructivist approach in developing procedural knowledge.

If rote learning is embedded in students' approach to practical work, the question arises as to why they fall back on rote learning. The answer may lie in the method of teaching used in classrooms. Traditional education involves transmitting knowledge to the students. Transmission of knowledge can be passively absorbed by the learner or actively assimilated with learners' prior knowledge, that is, meaningful learning may have taken place. One of the problems with passive learning is the reliance on rote memorization, repetition and imitation. This rote, arbitrary acquisition of knowledge is encouraged by poor evaluation practices as well as instruction strategies where a teacher rewards quick answers to questions that have little or no relevance to direct experiences with pertinent objects or events (Novak, 2002). Hassard (1992) in Novak (2002) emphasizes that "hands on" experience is not enough. Rather, a "Minds on" experience is equally essential to hands on experience.

2.2.3.1 Theoretical progress in the twentieth century

Duschl and Osborne (2002), in a comprehensive review paper on research into the creation of learning environments that enable dialogue in science classes, draw attention to the progress that has been made in the science education research community's understanding of how knowledge grows and develops. The authors note how, during the course of the twentieth century, theories of learning, mind and knowledge progresses **from**:

- Behaviourism (Trowbridge & Bybee, 1990)
- Belief in *tabula rasa* (Gilbert et al., 1982), and
- The notion that knowledge grows in a steady, cumulative fashion

to:

- an emphasis on the cognitive and social nature of thinking,
- the notion that children may have innate capacities (such as language syntax), and
- The recognition that knowledge is often reconfigured adapted and even abandoned.

In contrast to the behaviourist model of learning and teaching, the theory of constructivism accepts that learners are human beings and that a teacher's preoccupation should not primarily be the management of learners' behaviour. It rejects the view posited by behaviourists, namely that the learning-teaching enterprise may be approximated to the training and conditioning of dogs, cats and rats. (Trowbridge & Bybee, 1990)

It additionally, reflects awareness of an important insight when a teacher acknowledges and treats the learner as an active participant, rather than as one who arrives in class carrying an empty bowl (akin to the notion of a clean slate, or *"tabula rasa"*), hoping to have it filled with offerings of knowledge delivered by the teacher and to be passively received. The issue here is whether the human mind is a vessel to be filled. The point of departure is that no learner ever tackles the learning of a new concept in science from scratch, that is, from a state of total ignorance. The "*tabula rasa"* assumption, namely that a learner has no knowledge of a topic before being formally taught it, has been convincingly demonstrated to be invalid (Gilbert et al., 1982).

In light of such theoretical progress as has been outlined by Duschl and Osborne (2002), curriculum planners and teachers have been offered advice to try to:

1. centre classroom instruction around the learner's active learning, taking into account research findings that demonstrate that the learner's prior knowledge is a significant factor affecting learning;
2. Focus on procedural and strategic knowledge and not merely declarative knowledge.

In their monograph, Campbell, Lubben, Buffler & Allie (2005), require that undergraduate laboratory courses should improve students' scientific approach to enquiry, which is, developing students' knowledge of learning science. Montes and Rockley (2002), in Campbell et al. (2005), report that teachers show resistance to replacing traditional experiments by inquiry-type experiments as these may be more time consuming in terms of assessment.
Campbell et al. (2005), view procedural knowledge as a distinct domain of knowledge to be learned, rather than a collection of skills to be practised.

2.2.3.2 Constructivism foregrounds the role of learners' prior knowledge

The central tenet of constructivism is that the learner is not the passive recipient of knowledge but actively works to construct or acquire knowledge of the subject being studied. However, there are a wide variety of perspectives that are labelled "constructivist" (Geelan, 1997). Constructivist models of teaching and learning are based on the creation of a learner- and teacher-friendly classroom environment that builds on learners' prior knowledge, as opposed to authoritative classroom discourse (Scott, 1998). Such models support the provision of scaffolding, that is, teaching interventions that are sensitive to, and contingent upon, learners' needs. They also dignify learners who may be struggling to master new concepts in physics (Wood, 1991). The point about "contingency" is that the teacher's actions and interventions depend on what learners bring to the classroom. This renders learners' prior knowledge extremely important to the outcome of any teaching-learning activity.
The core commitment of a constructivist position is that knowledge is not transmitted directly from one knower to another, but actively built by the learner, (Driver, Squires, Rushworth & Wood-Robinson, 1994).

The constructivists call upon the learners to take responsibility for their own learning; this in no way implies that teachers need to relax in their teaching responsibilities. This simply means that a serious and responsible learner will try to obtain needed assistance with matters that are beyond the reach of his or her present knowledge and ability. It is really up to the learner to engage with the subject matter under discussion, to make personal (that is, to construct) the public knowledge

being considered in class, and to that end to exploit the resources available, including reaching out to the teacher's experience and knowledge of the subject area.

A constructivist's view of learning is dominated by two key considerations:

1. The need to take learners' prior knowledge into account when devising learning experiences;
2. The call to diminish the traditional reliance on, and move away from, meaningless(rote) learning and instead to pursue and encourage meaningful learning, that is, learning that involves actively linking new concepts with prior views held by the learner (Piaget,1964; Novak, 1977).

Wood (1991), states that teaching interventions are sensitive to, and contingent upon learners' needs. If teachers were made aware of their learners' prior knowledge, they would be well-placed to provide their classes with learning experiences that would use that knowledge as a starting point, very much the way any extension or renovation work planned for a building necessarily takes the existing structure as a starting point.

Cayhadi and Butler (2004:569), state that "getting students to recognize flaws in their mental models helps them develop their understanding" and that "a student's system of belief, observations, and understandings – whether correct or not, relevant or not, and correctly applied or not – are brought by that student to lecture, laboratory, and problems in class."

Leach and Scott (2003:92), refer to the Piagetian notion that "intelligence organizes the world by organizing itself", and explain that " according to this perspective, in order to predict how learners will respond to attempts to teach science it is necessary to understand the knowledge that students bring to a given teaching situation".

Constructivism has been said to be post-epistemological, meaning that it is not just another epistemology, or a way of knowing. It cannot replace objectivism. Rather, constructivism is a way of thinking about knowing, a referent for building models of teaching, learning and curriculum (Tobin and Tippin, 1993).

Constructivism also can be used to indicate a theory of communication. When you send a message by saying something or providing information, and you have no knowledge of the receiver, then you have no idea as to what message was received, and you can not unambiguously interpret the response. Viewed in this way, teaching becomes the establishment and maintenance of a language and a means of communication between the teacher and students, as well as between students. Simply presenting material, giving out problems, and accepting answers back is not a refined enough process of communication for efficient learning.

A constructivist perspective views learners as actively engaged in making meaning, and teaching with that approach looks for what students can analyse, investigate, collaborate, share, build and generate based on what they already know, rather than what facts, skills, and processes they can parrot. To do this effectively, a teacher needs to be a learner and a researcher, to strive for greater awareness of the environments and the participants in a given teaching situation in order to continually adjust their actions to engage students in learning, using constructivism as a referent.

In this study, in analysing students' responses an attempt will be made to determine students' trend of thought. The students' responses may give an insight into whether knowledge is being constructively developed or is it rote learnt. An important reflection when analysing the questionnaire in this study, was the question of whether or not the students actually transferred their mathematical knowledge of 'average' and 'graphs'. Campbell et al. (2005), in their monograph, based their tasks on the view that knowledge only has meaning within a socially defined context (Vygotsky, 1978). The tasks in the current study are adopted from Campbell *et al.* (2005). Campbell et al., (2005) has taken students' existing knowledge of measurement and uncertainty as the point of setting the questionnaire, therefore the current study has adopted the same.

The chapter proceeds to present review of the literature specifically related to this research.

2.3 Literature review

Scientific and technological advancement is based on one's ability to make reliable, accurate measurements. Analysis of measurements looks for patterns and relationships in order to reach valid conclusions. It is through practical work that a learner acquires a range of manipulative, computational, representational and interpretive skills, as well as a better conceptual understanding of the context and underpinning theory of the investigation. This review will focus on practical work, students' procedural knowledge and studies on repeating measurements.

2.3.1 Practical work

As stated in chapter 1, practical work has been used in high schools and tertiary institutions for various reasons and purposes. In general, the two rationales for practical work are:

- to facilitate the learning and understanding of science concepts, and
- to develop competence in the skills and procedures of inquiry (Millar, 1991).

These may be regarded as two distinct aspects of science performance. Despite the limitations of practical work expressed in some literature (Blosser, 1988), these two rationales remain what is generally expected of practical work.

The term practical has been defined as follows:

> *"Concerned with actually doing something"* (Advanced Learners' Dictionary) and *"Of, pertaining, or relating to the action of doing something; working; operation; method of working"* (Oxford English Dictionary)

From these definitions, it is evident that practical work must involve an action: an action performed by a learner. Klainin (1988) suggests that students should learn science by doing what scientists do. Scientists carry out experiments to verify laws, investigate observed events and formulate new laws; learners may go through the same procedures to gain conceptual understanding of phenomenon. Carin and Sund (1980), quoting John Dewey, the father of progressive education, mention that we learn by doing, and reflecting on what we do: there is evidence from psychology, and other sources, indicating that learning is not a passive process.

Practical work must involve the learner actively because practical study involves phenomena rather than concepts. However, examining phenomena develops concepts (Kapteijn, 1988: 191). At different levels of education, practical work may take different forms such as inquiry, discovery or guided learning, but it is imperative that practical work consists of investigations, exercises and experiences (Woolnough, 1991). Oslen, Hewson & Lyons (1996), state that the learning cycle has phases of exploration, conceptual invention, and expansion of concepts. Thus the inform-verify-practice (IVP) process of traditional teaching is only suitable for presentation of information (Oslen et al., 1996).

Another important element of practical work mentioned in the literature is that of process skills. Brotherton and Preece (1996:66), divide science process skills into two categories: basic and integrated skills.

- Basic skills involve observing, measuring, inferring, classifying, predicting, using numbers, using space/time relationships, recording and displaying data.
- Integrated skills involve interpreting data, controlling variables, defining operationally and formulating hypotheses.

It has been argued that the ability to observe, classify, hypothesize is something that every child possesses from infancy (Millar & Driver, 1987). This means that "process skills" need not to be taught. Children's ability to use them depends on the extent and confidence of their knowledge of the context they are asked to work on. Millar & Driver (1987), argue that the science process skills are untenable but acknowledge that 'processes' are utilized when investigations are undertaken. Millar (1991), uses the term "inquiry tactics", which a learner needs to, conduct an investigation. These inquiry tactics include repeating measurements and taking an average. The decision to repeat a measurement has a greater importance rather than the taking of the measurement itself. Millar (1991), proposes a model in which procedural understanding is divided into three categories. These are general cognitive processes, practical techniques and inquiry techniques.

- Examples of general cognitive processes are observing, classifying, hypothesizing, inferring and predicting.
- Examples of practical techniques are measuring, experimental procedures, recording and displaying data.

- Examples of inquiry techniques are repeating measurements to improve reliability and validity, drawing graphs to se trends, and identifying variables that need to be altered, measured or controlled.

Procedural knowledge is defined as 'knowing how' something works (Ryle (1949) in Novak (2002)) .According to the model proposed by Millar et al. (1994), in the PACKS study, procedural knowledge is seen as ; process skills, understanding of aims and purposes of scientific investigation and understanding of criteria for assessing and evaluating the quality of empirical evidence. This model is further discussed in section 2.3.2 of this chapter.

Millar (1991:44), suggests that practical work, should give learners, at all stages, appropriate opportunities to;

- Make observations;
- Select observations relevant to their investigation for further study;
- Seek and identify patterns and relate these to patterns perceived earlier;
- Suggest and evaluate explanations of the pattern;
- Design and carry out experiments, including appropriate forms of measurements, to test suggested explanations for the pattern of observations.

Lunetta (1988:169) summarizes practical skills as involving planning and designing, performance, analysis and interpretation and application.

However, much of the 'practical work' being performed at high school does not emphasis on data collection, processing and analysis skills. Students can go through the steps without even thinking about what they are doing and why they are doing them. With experience in laboratory outcomes, some students even change their results to suit the desired outcome. This is referred to as 'rigging' and 'stage-managing'. Johnstone & Wham (1980) suggests that students need to develop practical skills by carrying out these skills for themselves, under the guidance of professional personnel. Furthermore, White (1991:78), states that practical work must involve much more than mindless following of directions if useful learning is to occur during laboratory sessions. Woolnough (1991:181) expresses a similar perception as stated in chapter 1:

> "*There is still much practice of standard exercises, with students being expected to follow 'cookbook' instructions. The evidence is that such practical work does little to enhance*

students' understanding of concepts of science and nothing to enhance their appreciation of methods of science."

Practical work to develop students' scientific knowledge requires students to make links between two domains of knowledge; that of objects and observables, and that of ideas (Millar, Tiberghien & Le Marechal, 2002). Where the aim is to help students learn a concept, relationship, theory or model, the task design needs to 'scaffold' students' efforts to make these links. (Millar et al., 2002).

Millar (1991:44), suggests that practical work, as a process approach, should give learners, at all stages, appropriate opportunities to;

- Make observations;
- Select observations relevant to their investigation for further study;
- Seek and identify patterns and relate these to patterns perceived earlier;
- Suggest and evaluate explanations of the pattern;
- Design and carry out experiments, including appropriate forms of measurements, to test suggested explanations for the pattern of observations.

In conclusion, practical work must be an activity that imparts to the learner practical skills and conceptual understanding that will stand the test of time even after the learner exits formal schooling.

2.3.2 Procedural knowledge

Ryle (1949) in Novak (2002) suggests that knowledge can be classified as declarative or procedural. Declarative knowledge (sometimes called conceptual knowledge) is knowledge about something, whereas procedural knowledge 'is knowing' how to do something. In high schools practical work is used to teach students 'how something works', i.e. procedural knowledge.

Procedural knowledge is the ability to actually carry out an investigation and then take action based on the results obtained from investigation. Campbell, Lubben, Buffler & Allie (2005) define procedural knowledge as a distinct domain of knowledge to be learned, rather than a collection of

skills. Rollnick, Allie, Buffler, Campbell & Lubben (2004), point out that a component of procedural knowledge was earlier discussed by Burmeister (1952) and Lawson (1996) in Rollnick et al., (2004) who produced a modified list of Burmeister's components as follows:

1. Ability to accurately describe nature
2. Ability to sense and state causal questions about nature
3. Ability to recognise, generate and state alternative hypotheses and theories
4. Ability to generate logical predictions
5. Ability to plan and conduct controlled experiments to test hypotheses
6. Ability to collect, organise and analyse relevant experimental and correlation data
7. Ability to draw reasonable conclusions.

According to Millar *et al.*, (1994), procedural knowledge is subdivided into three categories: Use of instruments to carry out the investigations, understanding of the aims and purpose of investigation, understanding of the evidence (see figure 2.3.2.1)

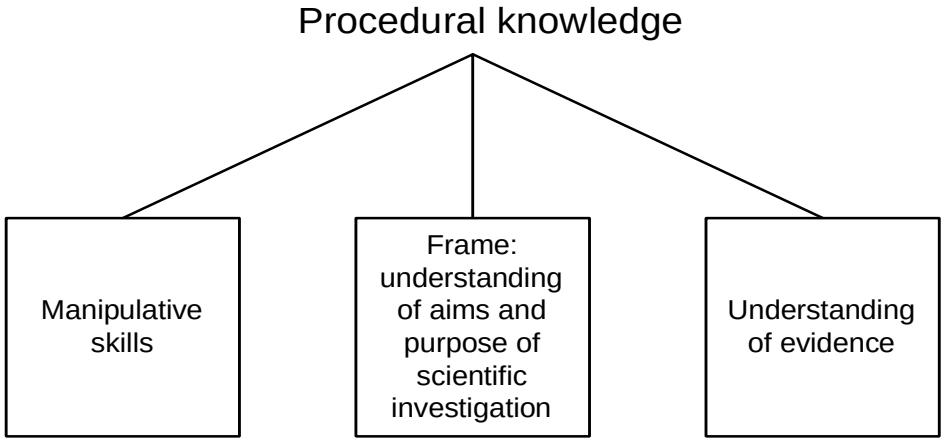


Figure 2.3.2.1: Components of procedural knowledge. Obtained from Millar, et al. (1994)

The first category, **manipulative skills**, refers to skills involved in the use of instruments and carrying out standard procedures. The second category, **frame**, refers to the understanding of the nature and purpose of the task, which leads to a choice of approach or frame to be used. Millar et al., (1994), found that some children tried to optimise the effect of variables when they should have clarified the relationship between variables.

The third category, **understanding of evidence**, refers to the understanding necessary to evaluate the quality of empirical evidence.

According to Millar (1991), general cognitive process cannot be taught, but rather can be enhanced with the use of practical work, whilst practical and inquiry techniques can be taught. Rollnick et al., (2004) present a theoretical model of students' thought processes when performing laboratory work. The three stages of the model are:

- Stage 1 – The pre-laboratory activity, in which some mastery of subject matter is required, or understanding the instructions for the procedure.
- Stage 2 – The experience in the laboratory, which will generate data, and finally ,
- Stage 3 – Writing of laboratory report, which is regarded as the crucial stage as the learner is required to process and analyze the data. This stage distinguishes between declarative and procedural knowledge.

This study will focus on stage 3 by determining students' understanding of processing and analyzing the given data.

Lubben & Millar (1996) in Campbell et al., (2005) suggested a model for the progression of types of student ideas about measurement; this will be used in the current study.

Table 2.3.2.1: Model of progression of ideas concerning experimental data. Adapted from Lubben & Millar (1996) in Campbell *et al.,* (2005)

Level	**Students' views of the process of measuring**
A	Measure once and this is the right value.
B	Unless you get a value different from what you expect, a measurement is correct.
C	Make a few trial measurements for practice, then take the measurement you want.
D	Repeat measurements till you get a recurring value. This is the correct measurement.
E	You need to take a mean of different measurements. Slightly vary the conditions to avoid getting the same results.
F	Take a mean of several measurements to take care of variation due to inaccurate measuring. Quality of the result can be judged only by authority source.
G	Take a mean of several measurements. The spread of all the measurements indicates the quality of the result.
H	The consistency of the set of measurements can be judged and anomalous measurements need to be rejected before taking a mean.

Gott & Duggan (1996) discuss procedural knowledge as the understanding of scientific evidence. Scientific evidence is based on the collection, analysis and interpretation of data. Evidence refers to understanding of criteria for assessing and evaluating the quality of empirical evidence (Millar *et al.*, 1994). Research by Millar et al. (1994) shows that many children draw their conclusions solely on the data collected, *i.e.* on the basis of evidence (but ignoring analysis and interpretation). This may lead to unreliable and invalid conclusions as it is imperative to analyse any data collected. This research seeks to understand students' ability to deal with the spread in the data as well as the presence of an anomaly.

Hackling & Garnet (1992) did comparative studies on the investigative abilities of expert scientists and high school students at four experimental stages: problem analysis, problem design, data interpretation, drawing conclusions.

The findings showed that the students had little awareness of the need to control variables and to repeat measurements. It was found that they did not make use of graphs to check the consistency of their data, and also did not consider the limitations and methodology of their experiments. This study focuses on the data interpretations specifically on repeat measurements.

In the UK, the widely adopted teaching materials of the Cognitive Accelerated through Science Education (CASE) project (Adey, Shayer & Yates, 1995), includes teaching ideas about variables, control of variables and experimental design. Teachers using these saw them as stimulating change in students' ideas and understandings. It is suggested that computer – based simulations may also help to reduce the 'noise' of the laboratory bench and focus attention on important aspects of experimental planning and data interpretation (Millar, 1999).

This study focuses on the understanding of evidence (Figure 2.3.2.1) with specific reference to data handling. Student's views on collecting, processing and comparing data are explored by classifying students' reasoning as "point" or "set".

2.3.3 Collecting data

Studies carried out by Duggan, Johnson & Gott (1996) used the different stages of an investigation at lower secondary school. The studies showed that students carried out practical work with no problems, but they struggled with handling the variables. This was further emphasised by Gott & Duggan (1996).

> *"Pupils have a reasonable grasp of the measurement phase, although they seldom repeat measurements. Ideas about data handling and evaluation are particularly poor".*

Lubben & Millar (1996) based their research on learners of age 11, 14 and 16 in the UK, to understand children's ideas about the reliability of experimental data. The emphasis was on: Reasons for doing repeated measurements, ways of handling data, ways of dealing with measurements.

This was achieved by giving learners certain probes, which explored some aspects of procedure, such as judgment of the significance of small differences between measurements in practical contexts. The need to repeat measurements was mostly understood by learners because they were always asked to repeat experiments by the teacher to get accurate results, however, little is said about what "accurate" is. The implication of the research is that understanding of reliability is part of a specific knowledge within science, which needs to be explored. Furthermore, the implementation and analysis of the probes gave an idea of students' progression in understanding of empirical evidence. A pattern of progression was determined according to age and experience. Here, the process of collection of data progressed from denial of the need to repeat measurements, to finding recurring results.

In further research involving understanding of empirical evidence, done by Allie *et al.*, (1998), it was found that language has an impact on students' reasoning. There seemed to be confusion about certain terms such as spread, range, uncertainty, precision and accuracy. This was also noted by Sere, M.G, Journeaux, R. & Larcher, C. (1993), on the understanding of 20 French physics undergraduates on issues relating to the quality of experimental results. In the monograph,

Campbell et al., (2005) refer to Tomlinson et al., (2001) who suggests that students should make use of a well-defined set of key words in practical reports.

Thomson (1997) suggests that teachers must teach learners to assign an 'estimate of error' to results in the laboratory, and that this error should not be confused with precision or accuracy. He went on to emphasize precision as an uncertainty based on statistical evaluation of the data (standard deviation), and accuracy as the known or accepted value. He further identifies that problems can arise due to the lack of differentiation between systematic and random errors in the minds of students. Many learners repeat experiments to get closer to the real or correct value; this implies that they intend to improve accuracy. Some learners repeated the measurements to determine the mean. This study focuses on determining if the students are point or set reasoners, that is, do the students find the need to repeat measurements to take the mean or to find a recurring value.

Kanari & Millar (2004) explored patterns in students' reasoning as they collect data in a practical science inquiry task and draw conclusions from it. Findings showed that repeat measurements were done unsystematically and students' oral comments showed that the most common reasons for repeating measurement was that the first one gave an unexpected value or to check and confirm the first value. The study further found out that students had much greater difficulty in interpreting data and in controlling variables suggesting that school science needs to include covariation and non-covariation into their syllabi.

According to Allie et al. (1998), meaningful engagement by students in scientific activities requires an understanding of the reasons for the procedures that are followed. Research carried out by Coelho & Sere (1998) and Evangelinos, Valassiades, & Psillos (1999), found that at high school level procedures are carried out without the reasons for the procedures being explicated. This shows a lack of understanding in carrying out a practical task. This may be due to either student's lack of understanding or due to teachers' lack of failure to explain reasons for procedures.

Campbell et al., (2005), in their monograph, investigated novice university physics students' understanding of measurement in scientific context. They found that students easily completed the questionnaire but, the analysis of the responses showed significant differences in students' decision making and reasoning. Over half the responses indicated that repetition is required in order to get closer to the 'real' or 'correct' value for the time or distance measurement. This shows that there is lack of understanding about measurement in scientific context. The probes in this study adopt a similar format thus; it seeks to make a comparison between students' decisions and reasoning. This is evident in the choice of answer and the reason provided for their choice.

A theory of measurement was developed from a grounded coding scheme by Allie et al. (1998), who focused on introducing the notion of measurement. The study was further used to classify the students as point or set thinkers, based on the same alphanumeric coding scheme.

Point reasoning is when learners think that each measurement is a true value and that each measurement is an independent measurement. There are no intervals; learners who tend to follow this trend of thought believe that only one single measurement is required to establish the true value (Lubben et al., 2000: 312).**Set reasoning** is a trend of thought, which is characterised by the notion that each measurement is only an approximation to the true value, and that the deviation from the true value is random. Hence a series of measurements (with the use of the mean and standard deviation) are required to find a true value (Lubben et al., 2000: 313).

Campbell et al. (2005) explored students' understanding of measurement by categorizing them as using either the point or set paradigm to make decisions on measurement for data collection. Students who do not repeat measurement were classified as point reasoners while those who took an average or considered the spread were thought of as set reasoners. If the students used rote learning to calculate the mean, they were considered point reasoners. This study adopts the same method of categorizing.

Research by Lubben et al., (2000) was carried out on 257 first year university students in Cape Town. A questionnaire comprising of seven written questions focused on three areas, *viz*, collecting data, processing data and analysis of data. Each question offered an alternative response, and students were asked to provide reasons for choosing the response. This kind of questionnaire

can raise the objection that responses were unnecessarily predetermined, and that recognition rather than understanding is tested. The questionnaire was analysed using the same coding system as in Allie et al.(1998) and Campbell et al., (2005) , and students were classified as point data collectors or set data collectors. In some cases interviews were conducted to verify their response.
The findings showed that students appeared to be consistent point or set reasoners, but seemed to have difficulty when there was a spread in the data. Some students showed that in some cases they used point reasoning, while in other cases they used set reasoning. There seems to be a lack of understanding in handling data.
The probes in this report, attempts to understand students views on handling data using a similar method as used by Campbell et al., (2005).

Further studies by Campbell et al. (2005) on first year science students showed that very few students repeated measurements, and those who did, repeated to confirm a measurement.

Campbell, Kaunda, Allie, Buffler & Lubben's (2000), findings show that students' knowledge of experimental procedures impacts on their observation and data collection process. This re-emphasizes the need to have extensive laboratory work experience and report writing at school level, with the teacher playing an active part in guiding the students through this process. The need to stress on curriculum in developing students' laboratory procedural skills with specific reference to measurement is highlighted by Buffler, Allie, Lubben & Campbell's (2001), research in which students tend to be drawn on an ad hoc basis to either the point or set paradigm.

Rollnick, Lubben, Lotz & Dlamini (2002), investigated students' understanding of data collection, data processing and data comparison, before and after students participated in two different introductory laboratory courses in South Africa. The study showed that there was a considerable shift from the point to set paradigm n order to take the mean of repeated measurements. However many students showed less progress in understanding spread in the data set. Extensive laboratory work and experience with data handling may alleviate this problem.

Repeated measurements research, done on a group of students, showed that some students seemed satisfied with one reading but if they did repeat, they were searching for a recurring value. The

group that did repeat and calculated the average not report on their findings. This shows a lack of reflective skills in report writing. Hence Rollnick et al. (2004), suggests a laboratory model as a tool to understanding students' performance in the laboratory in terms of factors that affect students' thinking process as well as distinguish between the students' declarative and procedural knowledge (Rollnick et al.,2004).

According to Vygotsky (1979), learning and development is defined in the "Zone of proximal development", essentially the space between the learners' prior knowledge and his/her conceptual understanding after the process of learning has occurred. Be it declarative or procedural understanding, students' prior knowledge should be the platform from which the teacher designs students' learning material in order to develop students' thinking.

It is usually assumed that there is a true value for a measurand and that each measurement that is performed in order to ascertain this value has some random scatter around this value (Campbell *et al.*,2005).Hence, the true value has no uncertainty. Campbell *et al.*, (2005) considered a probabilistic approach to measurement, in which student's prior knowledge about the nature of measurement is considered. This approach leads from the exact nature of a reading to the uncertain nature of the inferences about the measurand, of single and repeated readings.

This study focuses on grade 12 students' understanding of measurement. This research is based on Lubben et al.'s, (2000) work with point and set reasoning in practical science measurement by entering university freshmen, and first year students' perceptions of the quality of experimental measurements.

This report will now proceed to a discussion of the methodology employed in the study.

Chapter 3 – Research Design

3.1 Introduction

This chapter describes the research approach, research instrument and intervention, sample of students as well as ethical considerations and limitations of the study.

3.2 Research approach

The intention of this study was to gather data on learners' ideas about measurement by conducting a small-scale, cross sectional survey. Fraenkel and Wallen (1990) identified three major characteristics of a survey viz:

- Collect information from group of people
- Main way in which information is gathered is by asking questions
- Information is collected from a sample of people. In this case high school students.

The advantages of selecting a questionnaire are: it is cheap and easy to administer; it preserves confidentiality; it can be completed at respondents' convenience; it can be administered in a standard manner; it can achieve a high response rate and finally, corrections of any misunderstandings can be made Opie (2004:105).

An open-ended diagnostic test was chosen as the research instrument because they encourage broader, more detailed responses. The aim of the research is to determine students' thinking processes when handling data. The purposes of this study are best served by the use of predominantly open-ended questions. Foddy (1993:127), states that "*[p]roponents of the use of open questions argue that they allow [respondents] to say what is really on their minds without being influenced by suggestions from the researcher"*. The use of open-ended questions, therefore, makes it possible to minimize bias, which Cohen and Manion (1993: 302), define as *"a systematic or persistent tendency to make errors in the same direction"*.

A second advantage of the use of open-ended questions for this study is that the answers indicate the consistency of use of a point or set paradigm.

Opie (2004) discusses open-ended questions as questions that allow free response and no preconceived ideas, however, these responses may differ from respondent to respondent thus giving irrelevant detail. Coding responses can become difficult under these conditions.

3.3 Research technique

3.3.1 Justification

The questionnaire used in this study consists of open-ended questions where learners are asked to choose one option and justify their choice. Its format and development are described below.

The format of the diagnostic test was a multiple choice prompt followed by a request for the reason for the choice. Space was then provided for the students to write their response. The reason for the choice of this combination rather than just open-ended questions, which would give more insight into the student's understanding, was the students' difficulty in expressing themselves fully in the English language, and the students not having been taught the terminology necessary to discuss students understanding of reliability of the data.

According to Neuman (1994), the advantages of combining open and closed ended questions are:

- It is easier and quicker for respondents to answer – time is of great essence for grade 12 learners. A questionnaire that is quick to answer would not only keep them focused on the task but also create interest in completing the questionnaire.
- Easier to compare the answers of different respondents – each option is coded and linked to point, set or mixed reasoning. By choosing an option, the learners can be categorized easily.
- Answers are easier to code.
- Though the respondents have to make a choice in selecting one of the options, they are also free to express themselves. This gives the researcher an in-depth insight into the respondents' thinking process.
- Misinterpretation of the question can be noticed. This means that if a student chooses an option that suggests point reasoning, yet the explanation for choosing this option shows set reasoning, it indicates student either does not know how to handle data or is simply guessing it.

3.3.2 Format of research instrument

The questionnaire was selected from items in a similar survey devised by Lubben *et al*. (2000), that comprised eight written questions, referred to as probes (see appendix 2). The purpose of these probes was to investigate:

i. The decisions made by students while collecting data and a perceived need to repeat measurements.

ii. Procedural understanding when processing data as well as representing data to fit a straight line graph, is required.

iii. To explore students' understanding of spread in data.

All the probes related to the same experiment. A detailed diagram accompanied the text and the situation was demonstrated using a large-scale model. The probes were administered strictly in the sequence presented. Each probe presented a situation where a procedural decision was required, suggesting a number of alternative actions (A, B, C etc). Most importantly, a detailed reason for each choice was requested. All the probes had the same form; a number of options was presented by use of stickman characters. On completion, the questionnaires were collected and placed in an envelope.

The instrument in this study was adapted from Allie *et al.* (1998). The same format but a different context and probes were chosen because the researcher had successfully conducted a similar study previously, where the study on learners' ideas about measurements was divided into Physics and Chemistry. The Physics questionnaire was as used by Allie *et al*. (1998), and the Chemistry questionnaire was designed by the Chemistry Education Group, University of Witwatersrand. The context was changed to suit the grade 12 curriculum. Students were required to conduct an experiment to show how potential and kinetic energy can do work. To calculate kinetic energy, $E = 1/2mv^2$, the students needed to investigate how the distance the milk carton on the floor changes when the height of the ramp is varied. This was to enhance conceptual knowledge; however, in this study, students' procedural knowledge was under investigation and so to make it easier for students to relate with the context I decided to use the same context.

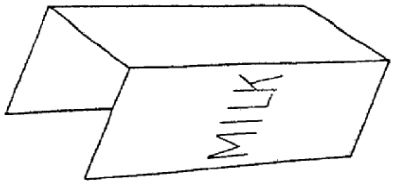
All the probes used the single context which appears in figure 3:

CONTEXT:

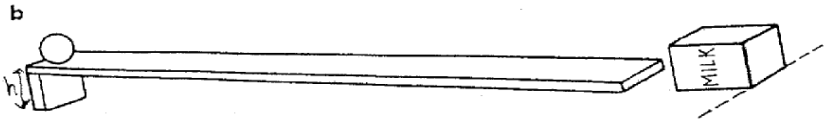
An experiment is being performed by students in the Science laboratory. The following instructions are given to the students to carry out their experiment.

Procedure:

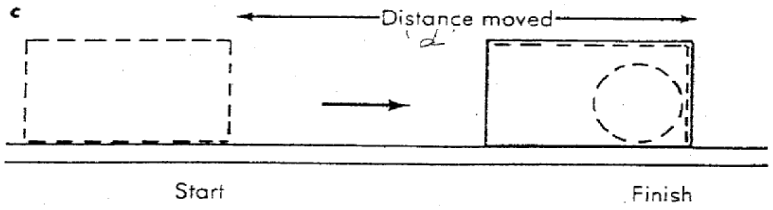
1. Cut the top and one side off the milk carton, as shown below.



2. Support one end of the board so that it is 10cm above the floor as indicated in diagram b .



3. Place the milk carton 10cm from the end of the ramp with open side down and the open end facing the ramp. Draw a chalk line along the closed end of the carton, also as in b.
4. Hold the ball at the top of the ramp. Release the ball and let it roll down the ramp and into the milk carton.
5. Measure the distance the carton moves along the floor, as in c



6. Repeat steps 4 and 5 three times, raising the ramp to 20cm, 30cm and 40cm above the floor.
7. Weigh the ball and the milk carton separately.
8. Calculate the potential energy of the ball when it is 10cm,20cm,30cm and 40cm above the ground.

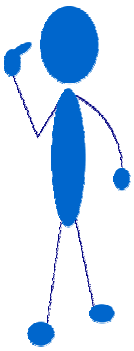
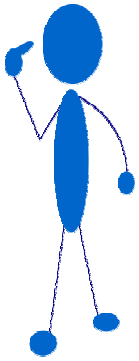
Figure 3.3.2.1: Context of questionnaire

The eight questions were in the form of probes about the context. For example, probe 1 is shown below:

Q1.

The students work in groups on the experiment. Their first task is to determine *d* when *h*=10cm. One group releases the ball down the slope at height *h*=10cm and, using a meter stick, they measure *d* to be 30cm.

The following discussion takes place:

I think we should roll the ball a few times from the same height and measure *d* each time.	Why? We've got the result already. We do not need to do anymore rolling.	I think we should roll the ball down the slope just one more time from the same height.
		
A	B	C

With whom do you most closely agree? (Circle ONE)

A	B	C

Explain your choice.

_____

_____

_____

_____

_____

Refer to appendix 2 for complete questionnaire.

The probes were designed to investigate data collection (probes 1-3), data processing (probes 4-6) and data comparison (probes 7-8). Their purpose is summarized in table 2 below.

Table 3.3.2.1: Summary of the probes.

DATA COLLECTION		
Probe	abbreviation	Name in full
PROBE 1	RD	REPEATING DISTANCE
PROBE 2	RDA	REPEATING DISTANCE AGAIN
PROBE 3	RT	REPEATING TIME
DATA PROCESSING		
PROBE 4	UR	USING REPEATS
PROBE 5	AN	ANOMALY
PROBE 6	SLG	STRAIGHT LINE GRAPH
DATA COMPARISSON		
PROBE 7	SMDS	SAME MEAN DIFFERENT SPREAD
PROBE 8	DMSS	DIFFERENT MEAN SIMILAR SPREAD

3.3.3 Research sample

This study was limited to 68 grade 12 higher and standard grade Physical Science learners between 16 and 18 years of age. The school is located in the northern suburbs of Johannesburg. The learners came from a middle class home background, and were mostly second language English speakers. The diagnostic test was implemented on a voluntary basis so the students could choose not to answer because of the ethical requirements of research. The test was conducted during their study hour at the end of the day. Only one school was chosen due to easy access, hence this study cannot be generalized because the study involved only one school which is not a representative of the “average” for South Africa.

3.3.4 Pilot study

A pilot study was done by trialling the questionnaire with five students. This allowed for the questions, time allocation, sequencing of questions, layout, coverage and language to be checked. Also, it allowed for any difficulties in understanding the questions to be identified.

However, the questionnaire was not found to have any substantive flaws. Minor problems were identified such as time allocation. 45 minutes was given to complete the questionnaire, but the students took one hour and 15 minutes. The experiment was demonstrated twice on students' request though they were familiar with the context. This showed a lack of confidence; therefore, they were assured that there was no right or wrong answer as the experiment did not require them to calculate kinetic or potential energy as in their practical session. The fact that the experiment had to be repeated forfeited the reason for changing the context of the experiment.

The other problem faced was that students had a tendency to go back to the previous question even though clear instructions were given not to do so. Out of the five students four of them knew which option to choose but faced difficulty in justifying their answer. To understand the reasons for this fully interviewing the students would have been the best and it may also have affected the results but due to time constraints this was not done.

Some printing mistakes were also identified as in probe 2; in both the releases distance was 60cm. The questionnaire was also not formatted in such a way to gain students attention hence the font size was increased and a clearer stickman was used.

As a result of the pilot study, changes were made to the procedures. The time allocated to complete the questionnaire was one hour and 15 minutes for demonstration. Students were made aware during the demonstration that there were to be no calculations involved; only their procedural knowledge was being tested. Each question paper was given a number and students were told that this was their reference number since they were not required to write their name. This number was to be quoted on each and every page, and as they finished probe 1, they were to detach it from the rest of the question paper and place it facing down. The supervisor would collect it immediately. This eliminated the temptation of looking back at the previous question.

3.3.5 Administration of the test

I administered the questionnaire; this was convenient as the school chosen to carry out the research was easily accessible. Verbal permission was taken from the Principal and Head of Department for

Science. This was easily obtained as I was a teacher in the chosen school. Students were briefed on the purpose of this test which would help in the research. The questionnaire was administered under exam type conditions. All students were asked to complete the questionnaire at the same time so that there was no discussion or influence from others. A time frame of one hour and 15 minutes was allocated to complete the questionnaire. The following instructions were given to students:

a) You do not need to write your name on the questionnaire

b) Please indicate your gender on the left hand side of the questionnaire on the front page. This will not be used in data analysis, however, if needed, it may be included.

c) The context of the questionnaire was explained carefully

d) You have been assigned a number; write this number on the top right hand side of every question. (This is to keep track on the questionnaire of each respondent)

e) Please read the questions carefully before you answer the questions. Once you have completed question 1, detach the page and place it facing down on your desk. It will be collected immediately. Proceed to the next question. (This was to ensure spontaneous thinking, and that students were not influenced by other questions and their responses.)

3.3.6 Coding system

The analysis of the probes consisted of categorizing the student responses according to the answer choice (A, B, C etc.) together with the different types of reasoning put forward by the students. The coding of the responses was undertaken using an alphanumeric scheme (appendix 3), which was developed and tested previously (Allie *et al.*, 1998). This enabled the underlying reasoning to be identified for each student in relation to data collection, data processing and data set comparison. The coding scheme works as follows and as described by Campbell *et al.* (2005), in their monograph:

Letter-Letter-Number – Number

1. The first letter was assigned for Point (P) and Set (S) reasoning/action to each response category. Where the responses (category or individual response) could not clearly be categorized as point or set, a (M) was assigned which designates mixed reasoning/action.

2. Where no reason was given or the response was uncodeable, a (U) was assigned unless the choice itself indicated Point action/reason.
3. The second letter indicates the choice of the student, e.g. An (A) was assigned if the student chose A, etc. No response was assigned an (U).
4. For the UR probe, letters were assigned according to the type of answer given, e.g. using all readings for the average calculation was categorized as an (A).
5. The first and second numbers were assigned in a logical manner, e.g. all responses including an average calculation in the RD probe was assigned a 2 as the first number and a second number according to the different category of responses within this group. A 3 was assigned as the first number for recurring readings, and a 1 for repeating for accuracy.

Some codes had to be introduced to fit the response of certain students. For example probe 3 codes added SE25 (Average to be more accurate) and SE21 (Average to take into account outside factors).

The above mentioned point and set reasoning has been described previously. Students who looked to repeat to get identical values are classified as using point reasoning and those who were inclined to take an average of a series of readings were regarded as using set reasoning.

3.3.7 Validity and Reliability

The reliability of coding was verified by having a sample of 20 responses to probes individually coded by 4 members of the Masters Program group as well as the supervisor. This ensured a common interpretation and application and enabled the consistency of coding to be checked. Each probe was independently coded by 4 members and an agreement was reached. Random samples were checked by the supervisor to ensure validation process. An agreement was reached to add codes if required and for results to be tabulated in a particular format. Furthermore a sample of 10 students was interviewed for about 10minutes to ensure their responses were understood and correct codes were allocated.

Extensive research has been carried out in South Africa on students' perception of measurements. Allie *et al*. (1998), studied first year Physics students' perceptions of the quality of experimental methods. They used a diagnostic test made up of written probes, which were then coded according to an alpha-numeric scheme, to look at students' ideas on reliability of experimental data. Their findings suggested that students follow a progression in understanding the reliability concept. This study uses a similar diagnostic test and coding scheme adapted from Allie *e .al.* (1998).
The diagnostic test was a credible research instrument yielding confirmable data because:

- The context of the question was familiar to the students as they had previously conducted an experiment under this context. The experiment was also demonstrated immediately before the students answered the questionnaire. The questions were written in as simple a manner as possible. The first 3 probes deal with data collection (repeating distance or time); the second probe deals with data processing(anomaly); the third probe deals with data comparison (spread in data).
- Cartoon characters were used to arouse interest and to prevent students choosing an answer because of gender or race bias (Allie et al., 1998).

Great care was taken to not make the test too easy or too difficult.

Furthermore, other researchers have used similar instruments as designed by Allie *et al.* (1998), which signify the reliability of the instrument. For example, Buffler et al. (1998) used a diagnostic test with nine probes to study pre-first year science students' ideas regarding the reliability of experimental data. They found that even those students that appear to be set thinkers do not fully understand the notion of spread. Set thinkers are able to think in terms of a set of measurements making up one measurement as opposed to thinking of each measurement as an individual measurement not connected to other measurements of the same point. This study also sees spread to be crucial to set thinking since a set of measurements of the same point can be represented by a mean and a spread.

Lubben et al. (2001), studied entering university freshmen's' understanding of reliability in practical science measurement. The point and set reasoning model arose out of studying the data. He found that the point and set reasoning model appears to be a useful classification scheme from which to make suggestions about teaching programmes to shift students' thinking away from point

reasoning and toward consistent set reasoning. Lubben et al. (2001), write that point reasoning is evidenced by students' thinking that each measurement could be the true value or not combining measurements, so measurement is perceived as leading to a 'point like' value rather than establishing an interval. Set reasoning is evidenced by the perception of a measurement as an approximation of the true value with the deviation from the true value being random, and also that a number of measurements are required to form a distribution that clusters around some particular value. This study adopts the same definitions on point and set reasoning.

Validity of data analysis of the probes was done by interviewing 10 students to explore students' understanding of the questions, as well as of the demonstrated experiment. The interpretation of their responses was verified. This enabled understanding of their reaction to the different probes and their overall impression of answering the probes. Some students had difficulty in writing down the answers but the interview made it easier for the student to express themselves. Due to time constraints not all the students could be interviewed. However it was found that 70% of these students' verbal interpretations were consistent with their written responses.

3.3.8 Ethical considerations

Verbal consent was taken from the students inviting them to participate in completing the questionnaire. It was made clear that this was strictly voluntary and attempting the questionnaire would have no implications whatsoever to assessment in the context of their grade 12 studies. Students would not be tested on knowledge needed for the successful completion of their studies, and no value judgement would be made. Strict anonymity of respondents was maintained by assigning them a random number. Students were explained the purpose of the study and reassured that all information would be used for research purposes only. Furthermore, permission from the Principal of the school, the GDE and the ethical procedures at Wits was obtained.

3.3.9 Limitations of the study

This project represents a qualitative study of limited scope, and makes no pretension to generalize the outcomes. It aims only to understand learners' process of reasoning during collection of experimental data. The limitations are:

- The sample is a convenience sample. The sample was selected because of the ease involved in gaining access to students, so that the study could be completed within the specified time allocation of the researcher's study period.
- The questionnaire consisted of only eight written questions of which some of the students' responses were uncodeable. Only 10 interviews were conducted to clarify their trend of thought because most students were not available due to study break.
- Though all the students who participated in this research were volunteers, some of the students' responses showed a lack of seriousness in answering the questions.

The report will next proceed to an analysis of the questionnaire that was conducted.

Chapter 4 – Analysis of Results

4.1 Introduction

The theoretical basis on which the expressions of respondents are analyzed is explained in some detail in chapter two of this report. The analysis of the responses was based on the coding scheme developed by Allie et al. (1998).

The analysis of the probes consisted of categorizing the student responses according to the answer choice (A, B, C etc.) together with different types of reasoning put forward by the students. The coding of the responses was undertaken using an alphanumeric scheme (appendix 3), which was developed and tested previously (Allie et al., 1998). This enabled the underlying reasoning to be identified for each student relevant to data collection, data processing and data set comparison. The coding scheme is adapted from the monograph of Campbell et al. (2005):

Letter-Letter-Number – Number

1 The first letter was assigned for Point (P) and Set (S) reasoning/action to each response category. Where the responses (category or individual response) could not clearly be categorized as point or set, a (M) was assigned that designates mixed reasoning/action.

2 Where no reason was given or the response was uncodeable, a (U) was assigned unless the choice itself indicates Point action/reason.

3 The second letter indicates the choice of the student, e.g. An (A) was assigned if the student chose A, etc. No response was assigned an (U).

4 For the UR probe, letters were assigned according to the type of answer given, e.g. using all readings for the average calculation was categorized as an (A).

5 The first and second numbers were assigned in a logical manner, for example, all responses including an average calculation in the RD probe was assigned a 2 as the first number and a second number according to the different category of responses within this group. A 3 was assigned as the first number for recurring readings and a 1 for repeating for accuracy.

Some codes had to be redesigned to fit the response of certain students. For example probe three codes added SE25 (Average to be more accurate) and SE21 (Average to take into account outside factors).
The above mentioned point and set reasoning has been described in detail previously. Students who looked to repeat to get identical values are classified as using point reasoning and those who were inclined to take an average of a series of readings were regarded as using set reasoning.

A sample of 20 responses to probes was individually coded by four members of the Masters Program group as well as the supervisor, to ensure a common interpretation and application and to check the consistency of coding. Each probe was independently coded by four members and an agreement was reached. Random samples were checked by the supervisor to ensure the validation process.

4.2. General observations about the data

All in all, there were 68 questionnaires collected from the learners. When classifying the data it was found that in the case of at least 10 of the questionnaires it was difficult to code the responses because most respondents really struggled to express themselves coherently and logically when talking about how many times measurements need to be repeated and reasons for taking an average. 10 of the questionnaires were therefore excluded from the results. Despite the fact that all respondents in this study were willing volunteers, a number did not feel confident about answering the questions. This may reflect insecurity in their knowledge of Physics. 15 of these students were interviewed to clarify their responses. Some of their responses were:

" I'm not good in physics",
"I'm not very intelligent"
"the teacher must tell us what to do, then we can calculate the average or take only one reading"
"You see, we always take 3 measurements, add them and take an average, that's the way to do it"

The above statements show a general tendency to rote-learning; this may be due the fact that what the teacher says is rarely questioned by the students. Hence knowledge is absorbed but not

constructed or the student's response may have been affected by the context of the questionnaire, which requires for three repeats. It is imperative to have critical thinking instead of following instructions. Practical work should be more interactive between teacher and students so that teachers assist the students through their individual "zone of proximal development", (Wretch, 1985).Students need to be taught to construct knowledge.

The report will proceed to discuss each of the probes.

4.3. Students' understanding of measurements.

4.3.1 Results of data collection.

Data collection

The first three probes are based on data collection for repeating measurements. The first probe deals with repeating distance (RD) and the question read as follows:

> The students work in groups on the experiment. Their first task is to determine *d* when *h*=10cm. One group releases the ball down the slope at height *h*=10cm and, using a meter stick, they measure *d* to be 30cm.
>
> The following discussion takes place:
>
> **A:** "I think we should roll the ball a few more times from the same height and measure *d* each time."
>
> **B:** "Why? We've got the result already. We do not need to do any more rolling.
>
> **C:** "I think we should roll the ball down the slope just one more time from the same height."

The next question was based on repeating distance again (RDA) and read as follows:

> The group of students decide to release the ball again from *h*=10cm.
>
> This time they measured *d*=28cm.
>
> First release: *h*=10cm *d*=30cm
>
> Second release: *h*=10cm *d*=28cm
>
> The Following discussion takes place:
>
> **A:** We know enough, we don't need to repeat the measurement again.

B: We need to release the ball just one more time.

C: Three releases will not be enough. We should release the ball several more times.

The last question for data collection was on repeating time (RT) and read as follows;

In order to calculate the speed with which the ball rolls down the ramp, the students are given a stopwatch and are asked to measure the time that the ball takes to stop once it is released from *h*=10cm.

They discuss what to do.

A: We can roll the ball once from *h*=10cm and measure the time. Once is enough.

B: Let's roll the ball twice from the height *h*=10cm and measure the time for each case.

C: I think we should release the ball more than twice from *h*=10cm and measure the time in each case.

In each case the learners were required to say who they agreed with and justify their response. As stated above, the choices and reasons were coded together.

Respondent's choice of option for each of the three probes was analyzed as follows. A sample of only 10 coded probes is listed below. For more detail refer to appendix 4. Each respondent was given an arbitrary number as a code. Each response was coded using the alphanumeric coding scheme (appendix 3). The table of analysis on the next page is to inform the reader how the results were recorded for analysis.

Table 4.3.1.1: Sample of coding method. (*n* =10)

Student code	RD probe	RDA probe	RT probe
1	PC35	PC35	PC30
2	PC32	PB35	PC35
3	PB40	PC35	PC35
4	PC35	MB15	PB35
5	PC35	PC35	PC35
6	PC35	PA40	PA40
7	SA22	SB25	MC15
8	PB30	PB30	PA30
9	PC32	PB32	SC28
10	PB50	SC21	MC15

Students coded as PC35 for the RD probe argued that:

> *If we roll the ball once it would give us a reading so we need to see if it is true. So we roll again to see if we get the same reading, then it is correct. (Student no.4)*

For the RDA probe code PA40 justifies:

> *Again one measurement is sufficient, they don't need to do another time if they are not instructed to do so, it will just waste time. (Student 6)*

And for the RT probe, the SC 28 code was assigned to:

> *Everytime we measure, distance will change, time will change, this will definetly (sic) happen so we just take an average. (Student 9)*

The responses were further categorized into six main ideas about the purpose of repeating measurements (Allie *et al.*, 1998). The codes were allocated as in table on the next page:

Table 4.3.1.2: Analysis of responses to RD, RDA and RT probes into six main ideas

Category	Description	Codes allocated to description.		
		RD	**RDA**	**RT**
R1	No repeats are needed	PB40,PB50 PB31,PC50	PA40,PA45 PA50	PA40
R2	Repeats provide practice to improve the process of taking measurements	PC32,MA15	PB32,MC15	MC15,MC80 MC10
R3	Repeats are needed to find the recurring measurement	PB30,PC32	PB35,PB30 PC30,MC80	PC30,PA30 PB30,PC32
R4	Repeats are needed to improve accuracy	PC35,MA61 PA35	PC35,MB65	PC35,PB35 MC15
R5	Repeats are needed for establishing a mean	SA22,SA25	SB25,SC21 SB28,SB20 SC25,SC24	SC28,SC20 SC25,SC21
R6	Repeats are needed for establishing a spread	0	0	0
R0	Not codeable	MA60,UCOO	MB40,MB60 MC40,UB01, UC01	MB40,UBOO UCOO,MC40

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Table 4.3.1.3 indicates the number and percentage of students that fall into each category:

Table 4.3.1.3: Summary of responses to probes RD, RDA and RT. (n = 68)

Category	Description	No. of students (%)		
		RD	**RDA**	**RT**
R1	No repeats are needed	12(18)	12 (18)	2 (3)
R2	Repeats provide practice to improve the process of taking measurements	5 (7)	3 (4)	8 (12)
R3	Repeats are needed to find the recurring measurement	16 (24)	14 (21)	15 (22)
R4	Repeats are needed to improve accuracy	17(25)	12 (18)	13 (19)
R5	Repeats are needed for establishing a mean	9 (13)	17 (25)	19 (28)
R6	Repeats are needed for establishing a spread	0	0	0
R0	Not codeable	4 (6)	5 (7)	6 (9)
R0	No Response	5 (7)	5 (7)	5 (7)

As referred to previously, there were quite a large number of unclassifiable responses, which were probed through interview. About five responses were blanks.

A large number of students opted not to repeat the measurement and were placed in category R1. One of the student's responses was as follows:

> *I say B because we have the result already. The same result will be obtained if we repeat the experiment. Why waste time.* (PC50) *(Student 66)*
>
> *I say B because why waste time if the teacher has not asked us to repeat.* (PB50) *(Student 10)*

Responses in R2 looked to achieving measure through practice:

> *If we do again and again, we will know how to roll the ball perfectly to get perfect answer*. (PB 30) *(Student 8)*

In the category of repeating to find recurring measurements, the response was as follows:

> *If they release the ball several times more and take measurements, some of the results may repeat themselves. Those will most probably be right. (Student 22)*

Category R4 stressed on repeats to get accuracy. One student wrote:

> *You need to release the ball a few more times until you get a correct answer. (Student 18)*

And another response was:

> *You need to achieve a more accurate answer. (RT response) (Student 59)*

Students who looked at calculating the mean in category R5 responded as such:

> *They can then work out the average time and should get a more reliable result. (RT response). (Student 41)*

Another response for the RDA probe was:

> *After the third time you can just take the average, it doesn't have to be perfect. (Student 14)*

None of the students were classified in the R6 category as none of the responses exhibited any knowledge of uncertainty in the measurement.

The analysis also showed that 25% of the learners for the RDA probe opted to repeat the experiment to take an average because it is the 'right way of doing things'. This may be due to the learners being exposed to 'recipe type' instructions, which are set out by the teacher in their worksheets or by the setting of the context which required for three repeats. The learners may never question this nor do the teachers explain it. However, 24 % of responses to the RD probe

reflect that learners repeat measurement to find a recurring value.

According to table 4.3.1.3, 28% of the students opted to take a mean for the RT probe as compared to RD (13%) and RDA (25%). Very few students opted for no repeats (3%) as compared to RD (18%) and RDA (18%). The results are very similar to that of Lubben *et al*. (2001), who also found that for time measurement, student's readings were quite different.

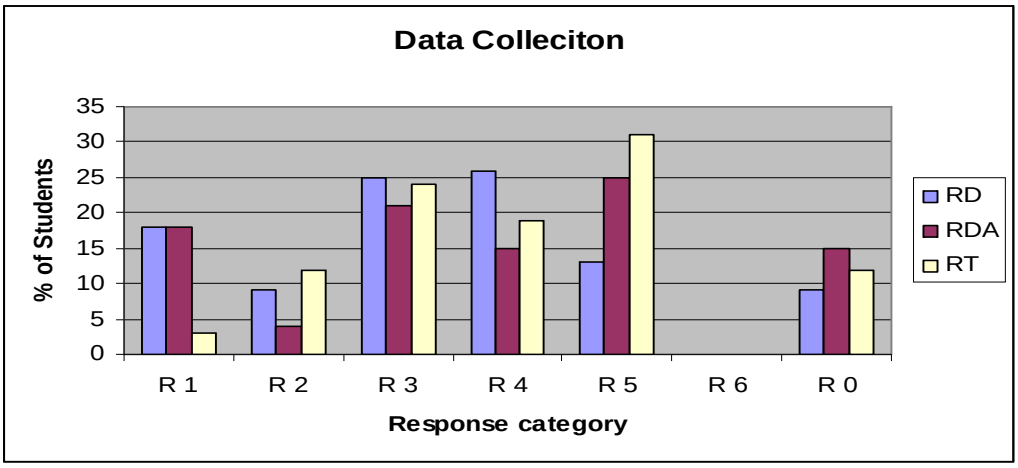

Figure 4.3.1.1Histogram to show analysis of Data collection

According to the histogram above it appears that for the RD and RDA probes 18% of the students in both the categories said no repeats were needed, however, there seems to be a change in their reasoning on repeating readings for R3 and R4, as they progress from question 1 to 2. It may very well be that the probes influenced their reasoning.

4.3.2 Results of data processing.

Probe 4 (UR) will be discussed later in the chapter along with probe 6 (SLG). Probe 5 deals with handling an anomaly as follows:

Another group of students have decided to calculate the average of their measurements of *d* for *h* = 10cm. Their results after six releases are:

Release	*d*(cm)
1.	35
2.	28
3.	31
4.	50
5.	31

6. 30

The students then discuss what to write down for the average of *d*.

A: "All we need to do is add all our measurements and then divide by 6.

B: "No, we should ignore *d* = 50cm and then add the rest and divide by 5.

As before students were asked to choose an option and provide their reasoning

The probe was analyzed for each respondent and the responses were coded and recorded as follows. A sample of the same ten students is shown. For more detail refer to appendix 4.

Table 4.3.2.1: Example of coding of probe 5. (*n* = 10)

Student No.	Code assigned		Student No.	Code assigned	
1	**B60**	**AN4**	**6**	**B60**	**AN4**
2	**B60**	**AN4**	**7**	**A61**	**AN2**
3	**A25**	**AN1**	**8**	**A25**	**AN1**
4	**B60**	**AN4**	**9**	**B60**	**AN4**
5	**B60**	**AN4**	**10**	**B61**	**AN3**

A code of B60 was assigned to those students who chose the letter B and argued that:

50 seems way out, so we must just leave it out. (Student 1)

Or

All the readings are very close accept 50, we must ignore it (Student 4)

Students with this code were categorized as AN4, which represents that the anomaly must be excluded as it is outside the acceptable range. This is further discussed in table 7.

Students with code B61 justified their choice of answer by stating:

If the experiment is not done properly, mistakes can be made, that is why they got 50. (Student 10)

Such a code was categorized as AN3; representing that the anomaly must be excluded as it is most likely a mistake.

A25 was allocated to those students who believed that all measurements need to be included to give a correct average.

When we calculate average we must take all the values, that's the correct way. (Student 8)

The above were categorized as AN1; the anomaly must be included when taking an average since all readings must be used. Table 4.3.2.2 shows how the anomaly was dealt with.

Table 4.3.2.2: Summary of responses to the AN probe. (*n = 68*)

Category	Description	No.of students (%)
AN1	The anomaly must be included when taking an average since all readings must be used.	18 (26)
AN2	The anomaly is noted, but it has to be included since it is part of the spread of results.	4 (6)
AN3	The anomaly must be excluded as it is most likely a mistake.	9 (13)
AN4	The anomaly must be excluded as it is outside the acceptable range.	27 (40)
AN0	Not codeable.	10 (15)

It can be seen from the table that 40% of the students chose to exclude the anomaly as most felt that it was too large a number to be included.

The difference is too great, ignore 50. (Student 21)

Or

6 readings are too many, 5 sounds reasonable, 50 is far off reading, so we can ignore it and jus take an average of the 5 readings. (Student 30)

26% of the students included the anomaly because they felt that was the right thing to do and that is how an average is calculated.

Why eliminate 50? Because the value is too high? No one said it was a mistake made during or before carrying out the experiment. I think it should be included. (Student 14)

Only 6% included the anomaly taking it as a spread of results.

The 4h drop could have a factor that the others don't. We see that it could happen and it's a true reading, therefore we need to include it. (Student 7).

It can be seen from table 5 that 40% of the students opted to exclude the anomaly while 26% chose to include it. The difference in AN1 and AN4 is almost double which shows that most students

made some sort of judgment about the data.

4.3.3 Results of data comparison.

Probe 7 and 8 investigated the reasoning used to compare sets of data. Both the probes promote consideration of the spread of measurements. As described by Campbell *et al.* (2005), the SMDS probe requires recognition of spread as a descriptor of the quality of a series of measurements while in the DMSS probe, the spread is an indicator of uncertainty (standard deviation) of a series of measurements.

Probe 7 dealt with comparing two sets of data with the same mean but different scatter as follows:

Two groups of students compare their results for *d* obtained by releasing the ball at *h* = 10cm. Their results for five releases are shown below.

Release	Group A	Group B
	d (cm)	*d(cm)*
1	37	36
2	32	50
3	31	25
4	35	31
5	33	35
Average	34	34

The students then discuss:

A: Our results are better. They are all between 31cm and 37cm. yours are spread between 25cm and 50cm.

B: Our results are just as good as yours. Our average is the same as yours. We both got 34cm for *d*.

Respondents were asked to choose an option and provide a reason

The responses were analyzed by assigning a code and the results tabulated as shown in table 4.3.3.1 on the next page.

Table 4.3.3.1: Example of coding responses. *n*=10

Student No.	**Code assigned**	**Student No.**	**Code assigned**
1	PB20	6	PB23
2	PB20	7	SA11
3	SA10	8	SA10
4	PB20	9	PB20
5	PB20	10	PB20

Students assigned the code PB20 argued that:

Average is the same, that's important. (Student 2)

Or code PB23

Both their results work out to the same average. The spread is not important. (Student 6)

Similarly students with code SA10 stated:

Well I would say A because the in B 90 is way up, at least in A it's much closer. (Student 8)

Or code SA12

By having a smaller range of results, there is less room for error. (Student 15)

The above results were further categorized as in table 4.3.3.2:

Table 4.3.3.2: Summary of responses to the SMDS probe (*n* = 68)

Category	**Description**	**No. of students (%)**
A	The results are equally good since the averages are identical.	45 (66)
B	The results of group A are better since the data of group A are closer together than those of group B.	20 (29)
C	Uncodeable	3 (4)

With reference to table 4.3.3.2, it can be seen that 66% of the students did not refer to the spread, hence implying that the spread has nothing to do with the quality of the measurements. A typical student's response was: "*Both their results work out to the same average. The spread is not important.*"

29% of the students concluded that the results of group A are better and seem to use the notion of spread in the data and in their conclusion. The overall responses suggest that the students are not able to differentiate clearly between overall spread of the data set and the differences between the individual data points within the set.

Finally, probe 8 dealt with two sets with different means but an overlapping (same) spread. The probe is as follows:

Two other groups of students compare their results for *d* obtained by releasing the ball at *h* = 10cm. Their results for five releases are shown below.

Release	Group A *d(cm)*	Group B *d(cm)*
1	30	28
2	25	30
3	28	25
4	24	26
5	30	29
Average	27	28

The students then discuss:

A: Our results agree with yours.

B: No, your results do not agree with ours.

Respondents were asked to choose an option and provide a reason

The responses for individual students were coded as shown in table 4.3.3.3:

Table 4.3.3.3: Example of coding responses for probes DMSS. *N*=10

Student No.	**Code assigned**	**Student No.**	**Code assigned**
1	PB20	6	PA20
2	PB10	7	PB20
3	PB20	8	MA45
4	PB25	9	PB20
5	PB20	10	PB20

A typical response for PA20 was:

The averages are close enough. (Student 6)

Or

We can't be perfect and anyway the averages don't differ by much. (Student 12)

PB20 responded:

The averages are not the same so the results do not agree with each other. (Student 5)

For MA45 the response was

The numbers are common even though it is at different times. The numbers are similar and so the difference in averages is acceptable. (Student 8)

Or

These results are in close similarity, the results do agree with each other. (Student 43)

The responses were further categorized as follows:

Table 4.3.3.4: Summary of responses to DMSS probe. (n =68)

Category	**Description**	**No. of students (%)**
A	It depends on how close the averages are.	63 (93)
B	It depends solely on the relative spreads of the data.	3 (4)
C	It depends on the degree of correspondence between individual measurements in the two sets.	0 (0)
D	It depends on both the averages and the uncertainties.	0 (0)
E	Not codeable.	2 (3)

From the above table it is clear that 93% of respondents compared averages only.

Some of the responses in this category are:

I think the results agree because the average is slightly different with only 2cm. (Student 10)

Another stated:

How have they agreed because the results are different? (Student 62)

And for category B, the responses were:

Because they have almost the same readings ,maybe just off by 2, so the average does not matter.(Student 20)

Or

Their results don't vary much, so average also does not vary much. (Student 65)

For the probe SMDS a large percentage (66%) of the students failed to consider the spread and for probe DMSS 93% did not again consider the spread but rather looked at how close the average was. Campbell *et al.* (2005), in the monogram also found similar results in that the comparison of data was not based on the spread. Students were unable to differentiate between the overall spread of data and the difference between the individual data points. Campbell *et al.* (2005), in their earlier studies on entering university freshmen, similarly found that students compared averages in order to come to a decision while less than 10% of the students compared the relative spreads of the data.

4.4. The use of a point and set paradigm of measurement.

In the above analysis of results the responses were allocated codes such as PB20 or SA20, P in the code stands for point paradigm and S for set paradigm. This section discusses the use of these paradigms by students across all of the 8 probes.

According to Lubben *et al.,* (2000):

Point reasoning is when learners think that each measurement is a true value and that each measurement is an independent measurement. There are no intervals; learners who tend to follow this trend of thought believe that only one single measurement is required to establish the true value. (Lubben *et al.*, 2000: 312)

Set reasoning is a trend of thought, which is characterized by the notion that each measurement is only an approximation to the true value, and that the deviation from the true value is random. Hence a series of measurements are required to find a true value, with the use of the mean and standard deviation. (Lubben *et al.*, 2000: 313)

Research by Lubben *et al*., (2000) was carried out on 257 first year university students in Cape Town. A questionnaire comprising of seven written questions focused on three areas, *viz*, collecting data, processing data and analysis of data. Each question offered an alternative response, and students were asked to provide reasons for choosing the response. The questionnaire was analysed using a coding system, and students were classified as point data collectors or set data collectors. In some cases interviews were conducted to verify their response. The findings show that students appear to be consistent point or set reasoners, but seem to have difficulty when there is a spread in the data. Some students showed that in some cases they used point reasoning, while in other cases they used set reasoning. This study similarly analyzed the responses and the following results were obtained:

4.4.1 Use of paradigm for data collection

For the three probes repeating distance (RD), repeating distance again (RDA) and repeating time (RT) probes, the responses were as follows for the point paradigm.

Students who thought one reading was sufficient and that repeating would waste time explained:

> *They won't have enough time to complete the practical, and if they do it gain and again they will get different answers everytime, so why waste time, one reading is enough. (Student number 35)*

Or

> *I say B because we have the result already. The same result will be obtained if we repeat the experiment. Why waste time. (Student number 40)*

Those students who chose to repeat the experiment to look for a recurring value justified their response by saying:

> *I agree with C, because by re-measuring, you can check if you get the same answer again so that you can make sure you are doing the right thing….. (Student number 33)*

Or

> *Repeat the experiment once more to get the same reading, and then you know you have done the experiment correctly. . (Student number 38)*

In contrast, students seeking to repeat measurements to calculate an average were classified as set reasoners. Samples of students' quotes in this favour are:

Once they have measured a few times they can work out the average. . (Student number 51)

Or

Well we must always work out average, so we need more readings; we must repeat the experiment a few times. . (Student number 39)

Some students thought three readings was a must to calculate an average:

Because you need a third measurement so that you can calculate the average distance. . (Student number 32)

Although the analysis and classification of the responses for each probe provide an overview for the ideas being used by the total sample of students, it is also useful to look at the set of responses of individual students in order to establish the consistency in reasoning viz, point/set. Some students may appear to be point reasoners but in actual fact they may be set reasoners, this cannot be determined fully as responses were coded on the interpretation of the reasons provided by learners and these learners were not interviewed or questioned about their reasoning.

The analysis also showed that some learners repeated the experiment to take an average because it is the 'right way of doing things', this may be due to the learners being exposed to the recipe type instructions, which is set out by the teacher in their worksheets. The learners never question this nor do the teachers explain it. However this is an area that needs to be further investigated.

The data were further analyzed as follows.If the student showed point or set reasoning for all three probes during data collection, then the student was considered as a consistent point or set data collector. If the responses showed a mixture of point or set reasoning then the learner was classified as a predominant point or predominant set collector, Q or R respectively.

The following are quotes from the same learner for the three probes which illustrate a consistent point data collector.

Probe 1

The ball should roll a few more times so that we can see if the first reading recurs. . (Student number 44)

Probe 2

Roll once more so that we can see which reading is repeated, and takes that as the correct answer.

Probe 3

So we can see which time we get twice and use that time.

The following are quotes which represent consistent set data collectors.

Probe 1

Repeating two more times will give us enough readings to determine an average. (Student number 20)

Probe 2

Release the ball just one more time, three readings is good to determine the average.

Probe 3

Doing it few more times can enable them to find the average and therefore the correct answer.

The table 4.4.1.1 (adapted from Lubben *et al.,* 2000) summarizes the consistency in reasoning for data collection. If the student expressed to be a point or set reasoner for the three probes in data collection, the student was considered to be consistent point or set collector. If the student chose two out of the three probes to be point reasoned then the student was considered as predominantly a point data collector and vice versa for predominantly set data collection.

Table 4.4.1.1: Frequencies of Point and Set Data collectors (n = 68)

Type of data collectors	**Code**	**Number of students (%)**
Consistent point data collectors	P	20 (29%)
Predominant point data collectors	Q	16 (24%)
Predominant set data collectors	R	8 (11%)
Consistent set data collectors	S	6 (9%)
Not classified	U	10 (15%)
Mixed data collectors	M	8 (11%)

Table 4.4.1.1 shows that just over 38% of the learners were consistent point or set data collectors of which 29% were consistent point data collectors and 9% were consistent set data collectors. 15% could not be classified and 11% were neither point nor set collectors.

The following are some quotes illustrating neither point nor set data collectors.

Probe 1

A, it's a sensible system …… No concrete reasoning is given. (Student number 24)

Probe 2

The answer B.…… No reason given. (Student number 24)

Probe 3

Friction causes this results ……… uncodeable. . (Student number 24)

32% of the students were inconsistent in their reasoning. Students in this group were set collectors for one probe but point collectors for the other probe. Some quotes to illustrate the responses from same student are:

Probe 1

So that you can make sure that the same result is obtained. (Student number 17)

Probe 2

So you can work out an accurate average distance.

Probe 3

So you can get an accurate answer or take an average.

4.4.2 Use of paradigm for data processing

Probes 4 and 6 were concerned with data processing. Probe 4 investigated students ideas about ways of representing and using repeated measurement (UR probe), while probe 6 dealt with students' response to fit a straight line graph to a series of plotted points (SLG probe).

Probe 4 was as follows:

The students continue to release the ball down the slope at a height h = 10cm. Their first five releases are:

Release	d(cm)
1	30
2	28
3	31
4	28
5	30

The students then discuss what to write down for d as their final results.

A: I think we should use d = 30cm

B: No, we should use d = 31cm

C: It is clear that we should use d = 31cm

D: I think we should use d = 28cm

E: I think we should use the averages of all the measurements which I have calculated to be 29,4cm.

Respondents were asked to choose an option and provide a reason

A sample of UR probe analysis is given in the table below:

Table 4.4.2.1: Sample of UR probe analysis from 10 students is given in the table below(n=10).

Student No.	**Code assigned**	**Student No.**	**Code assigned**
1	PD30	6	PD30
2	PD30	7	PC00
3	PA20	8	SE60
4	SE60	9	SE60
5	SE60	10	SE60

Students with the code PD30 looked for a recurring number and code PA20 represents students who chose to take the first reading, and felt repeating was not needed.

The following are some quotes to illustrate point processing:

31 is correct because it got to that answer twice. (Student number 6)

Or

The first release is the best release. . (Student number 3)

Or

30 seems like the best answer because it is in between and the last measurement. .(student number 55)

Some of the responses were classified as mixed as evidenced below is a quote.

30 seems like a correct answer, it just looks more central to other numbers. (Student number 60)

In the above quote the student could imply choosing one value or could imply looking for an average by the use of the term 'central'.

In contrast, set data processors calculated the arithmetic mean of the five measurements (30cm). In some cases students did not choose any options. According to them the average worked out to be 29,4cm.

The following are quotes to indicate set data processing.

The average is taken because it allows us to overlook the factors that could differ from drop to drop. (Student number 14)

Some examples of quotes to code SE60 are:

> *I agree with E. The average includes all the readings; I think stating just one reading will not reveal all the information. .(student number 12)*

Or

> *Because we never get constant numbers all the time, we use the average so that it's in the middle of all the answers. (Student number 13)*

Or

> *The calculated average is most accurate value among them*. (SA25) *(Student number 23)*

Or

> *Since the answers vary from each other, by calculating the average, you find the number closest to all the readings.* (SA 26) *(Student number 25)*

The next probe for data processing is the straight line graph probe. Analysis of this probe is based on the students' responses. Students' who drew a straight line to join the top and bottom points, or forced the line through middle points, or through the origin and top point, were considered as using the point paradigm. The following are some quotes in favour of this:

> *well I would take two points that are on the same line and draw a straight line. (Student number 2)*

Or

> *It should touch some points*. . *(Student number 32)*

Or

None of the above graph is correct because none start from the origin

In contrast, those students who considered all the points and looked for a best fit line were classified as set data processing. For example:

You need to draw a best fit line so that all the points are close by. (Student number 5)

Or

The trend line should have equal points to either side so that it's a best fit graph. .(student number 18)

Most students wrote that a best fit graph represents the average.

It shows average and that's the correct way. (Student number 28)

And

I think that in C the line of best fit shows the best average. (Student number 14)

The table below shows the frequency of point or set reasoning used across the two probes UR and SLG.

Table 4.4.2.2: Frequencies of Point and Set Data processing (n = 68)

Type of data processing	**Code**	**Number of students (%)**
Consistent point data processing	P	12 (19)
Consistent set data processing	S	38 (60)
Mixed data processing	M	13 (16)
Not classified	U	15 (4)

Table 14 shows that 60% of the students used set data processing. These students chose to take an average in the UR probe and took all points into account when drawing a best fit line in the SLG probe. This is in contrast to data collection where 20% of the students were seen to be consistent or predominantly set data collectors. 19% are classified as point data processors Students who used point paradigm in one probe and set in another were classified as mixed data processors. Most of the mixed data processors were those who used a point paradigm for data collection. Though they were consistent point data collectors, the UR probe showed set reasoning where some students looked for average.

4.4.3 Use of paradigm for data comparison

The last two probes 7 and 8 investigated the reasoning used to compare a set of data. Probe 7 dealt

with comparing two sets of data with the same mean but a different scatter while probe 8 provided two sets with different means overlapping (same) spread.

As discussed by Campbell *et al*.(2005), in the monograph on teaching scientific measurement at university: understanding student's ideas and laboratory curriculum reform, SMDS and DMSS probe both use set reasoning, however students responses that only focused on the mean were classified as **imposed** set reasoning. Those who considered the spread of the readings were identified as **internalized** set reasoning.

Examples of responses for students identified as imposed set reasoners are for the SMDS probe are:

> *Having different measurements really doesn't matter, but they both have same averages. (Student number 48)*

Or

> *It would not matter of how different the numbers are as long as the average is the same. . (Student number 22)*

For the same probe internalized set reasoning was identified as follows:

> *They are right (A) because their measurements are more realistic and have a less range between the biggest and smallest number. (Student number 17)*

Or

> *Even though the averages are the same, the variation in results in group B could caused a problem. (Student number 3)*

Very few students used an internalized set paradigm while some students were categorized as mixed set reasoners where for one probe the spread was considered but not for the other.

The table below shows the use of paradigms in data comparison for probes SMDS and DMSS.

Table 4.4.3.1: Use of paradigm in data comparison. (n = 68)

Paradigm used	Number of students (%)
Consistent imposed set paradigm	40 (59)
Consistent internalised set paradigm	0 (0)
Inconsistent set paradigm	18 (26)
No response	10 (15)

59% of the students across the two probes were identified as imposed set paradigm users. This

compares with the 26% of students exhibiting inconsistent set paradigm users. None of the students across the two probes were found to be using consistent an internalized set paradigm though in the SMDS probe few students looked at the spread in the data.

4.5 Conclusion

It seems from the analysis of the results that students are more inclined to use the point paradigm. Few students exhibit the use of a set paradigm by taking an average because it is the ‘right thing to do’, however there were still very few that along with the mean, considered the spread. This was not a clear indication of set reasoning right across the questionnaire as in the next probe they appeared to use point reasoning. Most students appeared to be set reasoners when processing the data as they seem to include all points when joining a line. Detailed discussion of the results will take place in the next chapter.

Chapter 5 – Conclusions and Recommendations

5.1 Introduction

At school I looked forward to practical work because I thought it was fun and nothing to do with the content learnt in class. Little did I know at that stage that practical work enhanced scientific conceptual knowledge and that both were part and parcel of learning science? At primary school, teachers told us exactly what to do, follow instructions but mostly practical work was demonstrated. We observed the end result. At high school, I was always exposed to instruction based practical work. In groups we followed the instructions and obtained our results. We never questioned the instructions and the teacher did not find the need to explain. We did practical work, because it was part of the syllabus.

At university lecturers assumed we had the knowledge of handling data, and most often we were left to find out on our own how to handle given set of data. Due to study pressure and lack of time the students resorted to what they knew best, follow instruction and get the end result. This procedure I have now come to see as an exercise in futility. The reason for adopting this view is the point made in chapter 2 of this report, namely that teachers need to learn about children's' science. The three main aspects were summarized as follows:

- Teachers ought to know how to explore the status of their learners' views on topics to be taught and learned;
- Teachers ought to determine the content and nature of their learners' views;
- Teachers ought to consider the various ways in which children's' science may, or may not, be modified by learning experiences.

Recipe-type laboratory exercises do not greatly increase the quantity or quality of decisions for which students are responsible. During such traditional exercises teachers are less likely to require students to carry out quantity or quality decisions simultaneously that neither they (teachers) encourage students' initiative (Oslen et al., 1996). So, students just go through the recipe without understanding. There is therefore value in using the idea of student autonomy to think about how

teachers handle laboratory work in their teaching. Students should have a good educational base for science. Science should not be taught as facts, principles, generalizations and laws, but as finding and ordering the data from our experience, which leads to these facts, principles, generalizations and laws. One of the approaches that could be used in order for students to become scientifically literate involves experiencing two phases of the discipline as proposed by Renner & Marek (1990:242), in the following quotation:

> *"The first phase concerns the gathering of data relative to the phenomenon under consideration, the actual interaction with the physical world. The second phase involves questing among the data gathered to establish relationships."*

Theory and research suggests that meaningful learning is possible in laboratory activities if students are provided with opportunities to manipulate equipment and handle data. Science teaching must take place in a laboratory as laboratory experiments are widely accepted by science educators as learning tools, for they are well integrated in curricular materials (Reiner, 1990). Regular pre and post practical discussions on how to deal with data can be a way of moving the students from rote learnt practical work to more interactive and meaningful practical work.

The procedural and conceptual knowledge in science (PACKS) (Millar et al., 1994; Lubben & Millar, 1996), explored the influence of procedural and conceptual knowledge on pupil's performance in investigative tasks and, in so doing developed a model of procedural understanding. A central feature of PACKS model is that procedural knowledge is knowledge based domain, similar to other science content domains, in that children come with prior knowledge and these knowledge needs to be developed through teaching. Scientific evidence contains ideas which must be taught --- (Millar et al., 1994:245). This evidence comprise of:
Design: variables identification, fair test, sample size, variable types;
Measurement: relative scale, range, interval, choice of instrument, repeatability, accuracy.
Data handling: tables, graph type, patterns, multi-variate data.

This chapter describes the findings, by summarizing the results of the analysis and describing their implications and also by answering the research questions.

5.2 Answers to research questions

The first research question of this study is: What are learners' views on collection of experimental data?

Based on oral discussions with the students it was discovered that they generally feel that practical work is only to help them get a better year mark, hence they do not place much effort and understanding into the process of practical work.

One important laboratory study is the large observational study of British secondary school children, entitled "Children's performance of investigative tasks in science: A framework for considering progression" (Lubben & Millar, 1996). Data in this study were collected by written survey instrument completed by 1000 students. It revealed the following three distinct areas of procedural understanding among students doing open-ended tasks:

- Students identify a variety of 'frames' for doing experimental work.
- Decisions about experimental procedures are influenced by students' knowledge about how to manipulate the apparatus.
- Students' understanding of the reliability of experimental evidence critically influences the procedure adopted (Lubben & Millar, 1996)

In the current study students views on collection of experimental data was understood by classifying them as point or set reasoners. Students who believed in using only one reading or repeated measurement to get recurring reading were classified as point reasoners. Those students who believed in taking an average and considered the spread in their decision were regarded as set reasoners. Though a very few students were true set reasoners, 75% of the students took an average because that is way it was always done. These students appeared to use both point and set reasoning, it is seen that their choice of the answer is not well justified by their response, this was also noted by Lubben et al. (2000).The understanding of the average was also noted; some students repeated measurements to take an average yet selected recurring reading. The use of point and set reasoning by the same students for different probes but within the same context *i.e.*, data collection, has been seen to be related to the procedural context. For instance, a number of overall

point reasoners adopted set reasoning when given two set of measurements, hence found the average but when no reading is given they seem to be content with the one reading and account for the difference in readings, if any, to lack of practice in using the ruler to determine the same reading over and over again. Campbell et al. (2005), in their monograph report that though the reasons for repeating in categories R2, R3, R4 (table 5) of the RT, RD and RDA probes appear to be different, they all seemed to either compare between individual readings or make a judgement on one set of readings. Hence there was no recognition that data set should be viewed collectively.

It was noted that there is little understanding for the use of point or set reasoning, though there is some consistency displayed across data collection and data processing but in some cases over the two probes they may appear to be point reasoner but in the third probe show set reasoning, this is similar to studies conducted by Rollnick et al.(2002). Rollnick et al. (2002), quotes Buffler et al. (2001), to describe these students as ad hoc or algorithmic set reasoners. Study by Sere et al. (1993) on the understanding of 20 French physics undergraduates on issues relating to the quality of experimental results showed that students differentiated poorly between random and systematic errors, and between the related low precision and accuracy of their data. They used laboratory observations. This study showed that students had specific difficulties in understanding the role and value of statistical tools in assessing confidence in measurement (McDermott & Redish, 1999).

The next two research questions will be discussed together as learners' understanding of repeating measurements, are inter-related. The questions are:

2. What understanding do learners have about why readings should be repeated to collect a set of data?

3. What understanding do learners have about the factors that should be taken into account in processing and comparing data sets?

The inconsistency in reasoning used for repeating measurements clearly indicated that students were confused as to whether repeats were required or not, if they were, most students were inclined to take an average however the reason was because that is what they were always told to do. This shows rote learning. Consistency in their reasoning was seen in the RD and RT probes unlike in studies conducted by Allie et al. (1998), who reported on finding of a study of mainly

Science Foundation Programme students at the University of Cape Town. Data were gathered by written probes. Fewer students perceived the need to determine a mean for distance measurements than for time measurements, indicating that procedural understanding depends on measurements being made.

By and large the studies show that students did not appreciate the need for error analysis. This is evident from responses to the DMSS and SMDS probes which focus on using the spread around a mean to compare whether two sets of measurements are consistent with each other. Most of the students are seen to be spread reasoners, however there is a small group of students that appear to be spread reasoners for repeating measurements (RT probe) but not DMSS probe. Students recognize that there is a spread but do not know how to synthesize this information. In comparing the DMSS and SMDS probe it is noted that though the spread was recognized in the SMDS probe, only few students applied the criterion of spread in the DMSS probe. In other words 20% of the total sample is regarded as using reasoning in a consistent way. Campbell et al. (2005), in their monograph report that 15% of the total sample of students is in consistent in 'spread reasoning'. They further conclude in SMDS probe a good proportion of students might have understood the notion of spread but for the DMSS probe only the average was recognised while the scatter was ignored. The same observation is made in the current study. Kanari & Millar (2004), in finding out students' ways of reasoning from data concluded that repeat measurements were done unsystematically. Student's oral comments show that the most common reasons for repeating a measurement was to reconfirm the first value. In the process of collecting data students selectively recorded and replaced values in their data set to show a trend, or selectively considered only those repeats that fitted the trend. (Kanari & Millar, 2004).

In conclusion it can be said that though a large percentage of students appear to be point reasoners, they may be set reasoners and vice versa as the term average is used yet a recurring value is taken, this cannot be established as analysis was based on written responses, students were not approached to clarify their statements. The results of this research overlap with the findings of Lubben et al. (2001), where students appeared to be consistent point or set reasoners, but seemed to have difficulty when there is a spread. Though students appeared to understand why readings should be repeated when dealing with data collection, they showed great difficulty in handling this

data in the DMSS and SMDS probes as discussed earlier. Only one student showed the level of sophistication in reasoning when dealing with an anomaly. This shows that though the correct procedures are followed learners have little or no understanding of the factors taken into account during data collection and processing. The inconsistency in the use of paradigm is also noted by Campbell et al. (2005), in their monograph. Differentiation between reasoning about measurement and measurement action for each paradigm is illustrated in table 16, adapted from Campbell et al. (2005), from their monograph.

Table 5.2.1: Actions and reasoning associated with point and set paradigms. (Adapted from Campbell et al.,.2005)

Point Paradigm		
Measurement phase	**Action**	**Reasoning**
Data collection	No repeating of measurements is necessary, or repeat to find recurring value, or repeat for practice.	A measurement leads to single, 'point-like' value rather a contributing to an interval. Only good measurement is required.
Data Processing (calculation)	A single (best) measurement, e.g. the recurring value, is selected to represent the true value.	Each single measurement is independent of all others and can in principle be true value.
Data Processing (straight line graph)	All points joined by multiple line segments or a single line drawn through selected data points.	The trend of the data is best represented by selecting particular data points which describe the desired trend.
Data set comparison	A value-by-value comparison of the two sets, or comparison based on the "closeness" of the means (if given).	No basis for the need to repeat measurements therefore comparisons made on the basis of closeness of individual points.
Set Paradigm		
Measurement phase	**Action**	**Reasoning**
Data collection	Repeating of measurements of the same quantity is necessary as a consequence of the inherent spread in data.	Each measurement is only than approximation to the true value and that the deviation from the true value is random. A large number of measurements are required to form a distribution

		that will cluster around some particular value.
Data Processing (calculation)	A set of measurements is represented by theoretical constructs, e.g. the mean and standard deviation.	The best information regarding the true value is obtained by combining the measurements using theoretical constructs in order to characterise the set as a whole.
Data Processing (straight line graph)	All the measurements taken into account by a least squares straight line to fit to all data.	The best graphical representation of series of measurements is obtained by modelling the trend of data.
Data set comparison	The agreement of two measurements is related to the degree of the overlap of intervals.	The mean and standard deviation define a confidence interval which is related to both the best estimate and the reliability of the measurement.

Most students exhibit set reasoning as rote learnt, this may be due to the traditional laboratory course work. Hence a recommendation to the teachers would be to shift students reasoning from point to set paradigm as seen in the figure below also from Campbell et al. (2005), from their monograph.

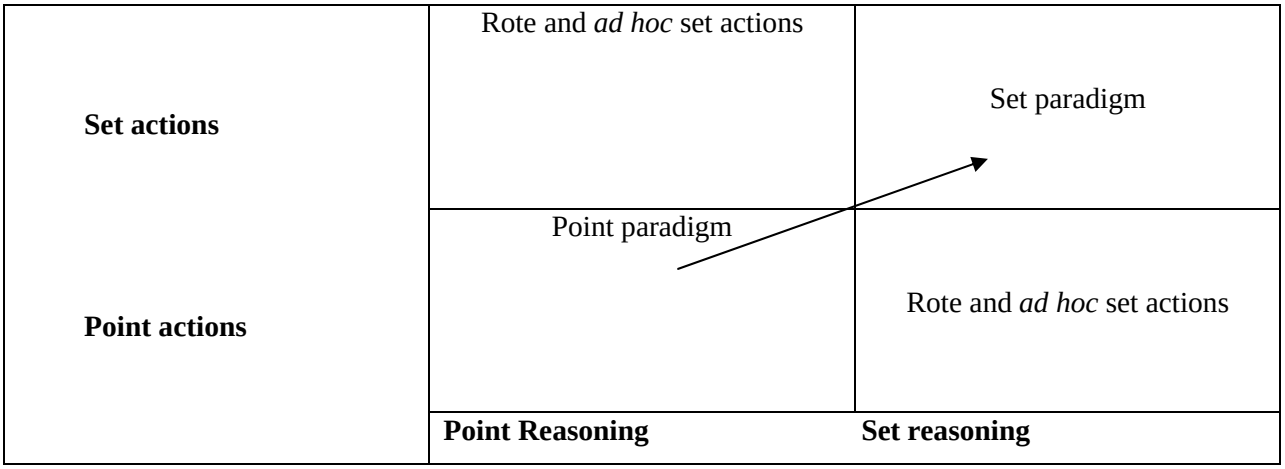

Figure 5.2.1: The goal of instruction in relation to point and set paradigm.

5.3 Reflection on the Study

The questionnaire used in this study proved to be a useful tool in investigating learners' ideas of measurement. The context of the questionnaire was well understood by the students and so were the probes, if there was any difficulty on the part of the students, it was in limited language skills. A well designed diagnostic test is able to test student understanding and is quick to administer Opie,(2004:105), there are no wrong or right answers which puts the student at comfort and the student is able to give reason on why certain answer was chosen, this would give insight to students reasoning. However in some cases it was felt that interviews were necessary as the students reasoning could not be coded. As I was familiar with the school and school context it was easy for me to administer the questionnaire and also was aware of the strong and weak students as well as the English 1st and 2nd language learners.

As explained in chapter 3, the context of the questionnaire was changed so as to make it easy for the students to understand as this was familiar to them. But it proved to be a fruitless exercise as some of the students still faced difficulties. It also was not a good idea to alter the questions because in adapting the questions there have been risks to the spread in the data and well as mistakes in the questionnaire which may have had an impact on the results. Though I was very careful in selecting the readings, some misprints were made and miscalculations as well, which are discussed below. The questionnaire was related and adapted from the study conducted by Lubben *et al*. (2000), hence this study's coding scheme and method of analysis was guided by previous studies conducted on learners' ideas about measurement on entering university students in South Africa.

Some of the problems related to the questionnaire are:

- In the context of the questionnaire it required three repeated readings, yet probe 1 and 2 asked students to make a judgment on how many repeats were needed, if any. Despite the fact that the question asked for repeats, there were students who opted for no need to repeat. The slight contradiction between the context and probes 1 and 2, may have led the students to opt for option A, in probe 1 and option C, in probe 3. In the UR probe Students with code PD30 looked for recurring number and code PA20 represents students who chose to take the first reading, and felt repeating was not needed, this shows that despite the fact that the questionnaire required for 3 repeats, some students opted not to.

- Probe 4 has two identical options (B and C); this did not affect the analysis of results as the students explanations were mostly relied on. Another mistake in the same probe was the mean of 29,4cm for option E; this should have been given in 2 significant figures like the rest of the readings i.e. 29. Some students did not choose any of the options; this may have been due to the difference they may have found in their calculation and what was on the paper.
- Probe 5, option B contains a misprint (80cm should be 50 cm). This error could have caused students to opt for option A as option B was incorrect. From a student's perspective the incorrect response could have been purposeful, and could lead the student to think that the question is in fact giving a hint on the choosing option A. This may have affected their reasoning on measurement.
- In probe 6, the stem says that the same data are being plotted by all the students, but the plotted points as provided for the different options are very different. This again is a mistake in providing the correct information to the students. The aim of the question was to determine how students use the data to plot a graph, i.e. do they join all the points, or join the highest and lowest point or draw a best fit line? This did not affect the results as irrespective of the data given, the aim of question was to identify student's skill of plotting a graph. Students who drew a straight line to join the top and bottom points, or forced the line through middle points, or through the origin and top point, were considered as using the point paradigm. In contrast those students who considered all the points and looked for the best fit line were classified as set data processing. Students' responses to their choice made it clear that their responses were not affected by the mistake in the probe.
- The average in probe 7 is incorrect. For group A average is worked out to be 33,6cm rounded to 34cm but group B's average is 35,4cm i.e. 35cm. From the students responses it seems that students took the average as given and did not calculate the average for group A and B. This then does not affect the results as the students may have or have not taken the anomaly into consideration. Those students who chose not to answer the question have seen the mistake and hence avoided to answer.

Many students were unclassified 10 of which were excluded from the sample analysis due to either blanks or being uncodeable, hence having an impact on the analysis of results. Due to many mistakes in the questionnaire, there are threats to the reliability and validity of the research. As the

study was based on a very small sample of students, the knowledge produced cannot be generalized to other people or other setting.

5.4 General recommendations

Generally most of the students were predominantly point reasoners and showed a lack of understanding in handling data. From the findings in this study, this could have been due to the following:

- Lack of prior exposure to practical work due to teacher demonstration or exposure to recipe type practical work.
- Teacher's interest in enhancing declarative knowledge through practical work but no or little importance given to the reliability of the data by dealing with precision and accuracy, importance of spread and range in the data, experimental error, uncertainty.
- Teachers may not be aware of the seriousness in teaching students how to deal with set data during their practical work.
- Teachers may not be aware of the reasons for repetition.
- Students' lack of interest in math, hence calculating an average or mean may be a tedious job, and therefore may resort to looking for recurring number.

The following recommendations are put forward for curriculum planners and teachers:
Laboratory work must be designed in such a way so as to acquire skill and confidence in their:

- measurement of physical quantities with appropriate accuracy
- recognize factors that may affect the reliability of their measurements
- manipulation of laboratory tools
- clear description of their observations
- representation of information in appropriate verbal, pictorial, graphical, and mathematical terms
- inference and reasoning from their observations
- ability to rationally defend their conclusions and predictions

- Students' practical skills need to be assessed as they carry out their laboratory activities. This would instil a sense of seriousness among students.

Learners come to laboratory with imagination, curiosity and argumentativeness to which the teacher can hope to add scientific purpose, logical method and practical skill in order to come up with an understanding of scientific theory. Integrated process skills develop gradually and reach a higher level of sophistication when experiments are performed in a meaningful context.

5. 5 Research recommendations

The data presented in this study calls for a number of questions that can be answered by further research. Listed below are some suggested areas of research.

- To investigate the relationship between students' mathematical skills and their ability to analyse data.
- To investigate if the new FET curriculum has made a positive impacted on learners understanding of handling data. This means that having moved away from the recipe-type practical work, has there been a shift from point to set reasoning?
- Investigate if teacher's ways of conducting practical work has an effect on how students handle data.
- Does language influence the kind of reasoning used by students' *i.e.,* first, second and third language English speakers.

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APPENDIX 1

Effect of Height on Potential Energy

In groups of 4 , carry out the following practical.

Materials
-toy car
-6 text books
-tagboard or other material for track
-3 one-cup milk cartons
-meter stick
-tape

Follow the instructions:

Procedures:
1.Place the track so that one end is on top of ONE of the books, and the track slants down to the floor (or table). Tape the track to the floor so that it does not move.
2.With the cartons, build a tower at the lower end of the track. Two cartons should be on the bottom of the tower; one carton should be on the top.
3.Place the car at the top of the track and allow the car to roll down the track (DO NOT PUSH THE CAR).
4.Measure from the bottom of the track to the carton that was knocked off. Measure the distance in centimeters (meters, if necessary) from the lower end of the track to the edge of the carton that is FURTHEST from the track. If the car did not knock over the cartons, record this information. Repeat three times and record information.
5.Raise the track so that one end is on top of THREE books total now. Rebuild the tower of cartons.
6.Place the car at the top of the track and allow the car to roll down the track. Measure how far the carton traveled in centimeters. Repeat three times and record information.
7.Raise the track so that one end is on top of SIX books total. Rebuild the tower of cartons.
8.Place the car at the top of the track and allow the car to roll down the track. Measure how far the carton traveled in centimeters. Repeat three times and record information.

Recording and Analyzing Data:

ONE BOOK	THREE BOOKS	SIX BOOKS
Trial 1: cm	Trial 1: cm	Trial 1: cm
Trial 2: cm	Trial 2: cm	Trial 2: cm
Trial 3: cm	Trial 3: cm	Trial 3: cm

Questions:

1.How did the height of the hill change in your demonstrations?
2.What kind of energy did the car have at the top of the hill?
3.What kind of energy did the car have as it was rolling down the hill?
4.When did the car have the least energy-----at one, three, or six books? When did the car have the most energy?
5.How does the height of the hill affect the amount of potential energy in the car?

APPENDIX 2

QUESTIONNAIRE

Please fill in this questionnaire to help me with my research project.

The information you give will not be used for your academic record.

All information you supply will be confidential.
Any quotes will be made anonymously and the information will be used for teaching and research only.

Thank you for your assistance.

DATE: _____

Time allocation: 1hr 15minutes

INSTRUCTIONS:

1. READ THROUGH THE CONTEXT OF THE EXPERIMENT THEN ANSWER THE QUESTIONS THAT FOLLOW
2. THERE ARE EIGHT QUESTIONS. EACH ONE IS PROVIDED WITH DIFFERENT OPTIONS
3. CHOOSE THE OPTION YOU AGREE WITH THE MOST. THERE IS NO WRONG OR RIGHT ANSWER
4. PROVIDE REASONS FOR YOUR CHOICE IN THE SPACE PROVIDED
5. YOU MAY NOT GO BACK TO A QUESTION ONCE YOU HAVE FINISHED.

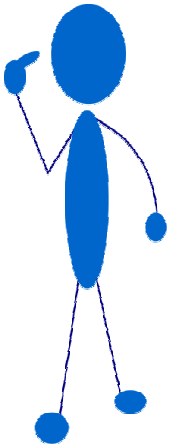
1

Probe 1

The students work in groups on the experiment. Their first task is to determine *d* when *h*=10cm. One group releases the ball down the slope at height *h*=10cm and, using a meter stick, they measure *d* to be 30cm.

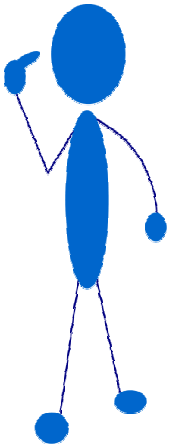
The following discussion takes place:

I think we should roll the ball a few times from the same height and measure *d* each time.



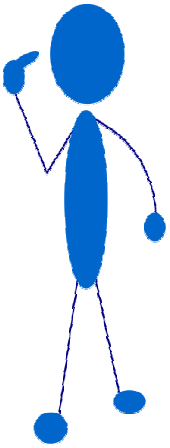
A

Why? We've got the result already. We do not need to do any more rolling.



B

I think we should roll the ball down the slope just one more time from the same height.



C

With whom do you most agree? (Circle ONE):

A	B	C

Explain your choice.

_____

_____

_____

_____

_____

Probe 2

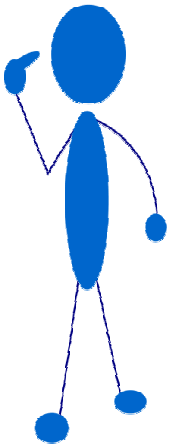
The group of students decide to release the ball again from h = 10cm. This time they measured d = 28cm.

First release: h=10cm d=30cm

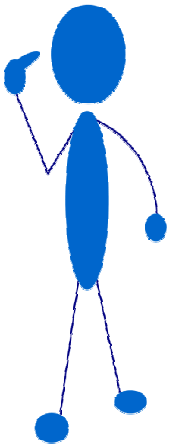
Second release : h=10cm d=28cm

The following discussion takes place between the students.

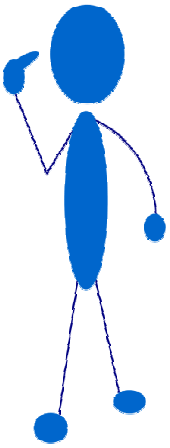
We know enough, we don't need to repeat the measurement again.	We need to release the ball just one more time	Three releases will not be enough. We should release the ball several more times.



A



B



C

With whom do you most agree? (Circle ONE):

A	B	C

Explain your choice.

_____

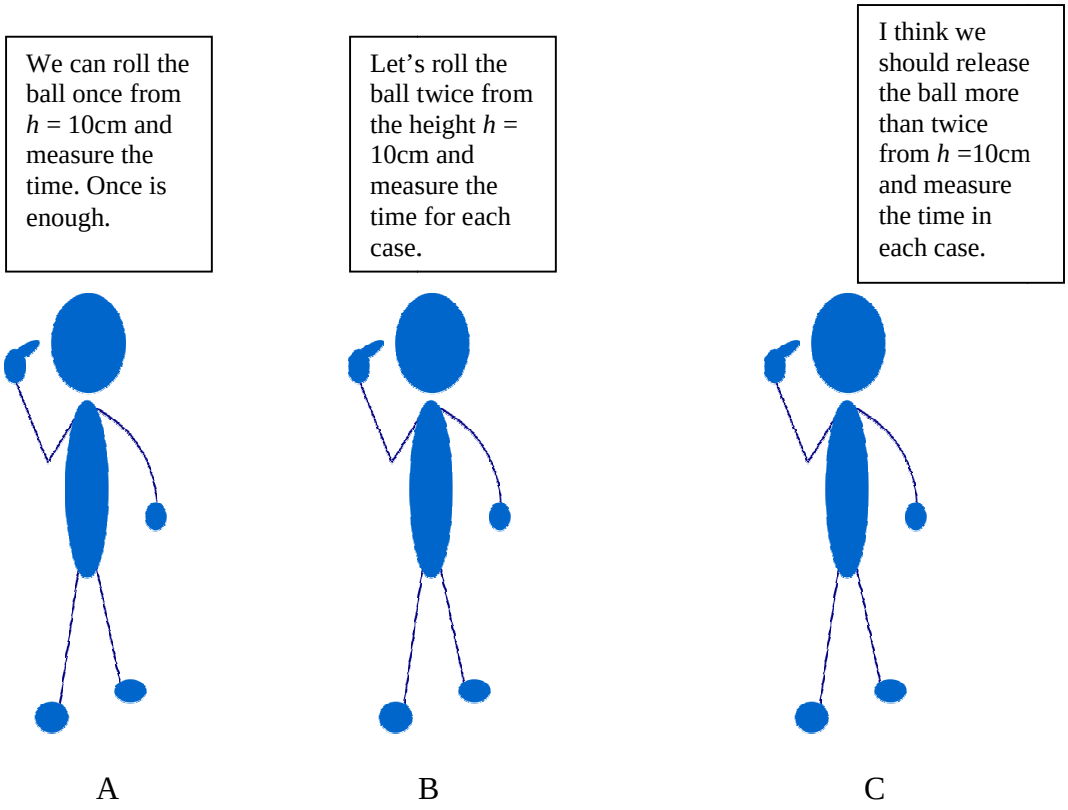
_____

_____

_____

Probe 3

In order to calculate the speed with which the ball rolls down the ramp, the students are given a stopwatch and are asked to measure the time that the ball takes to stop once it is released from h = 10cm. They discuss what to do.



With whom do you most agree? (Circle ONE):

A	B	C

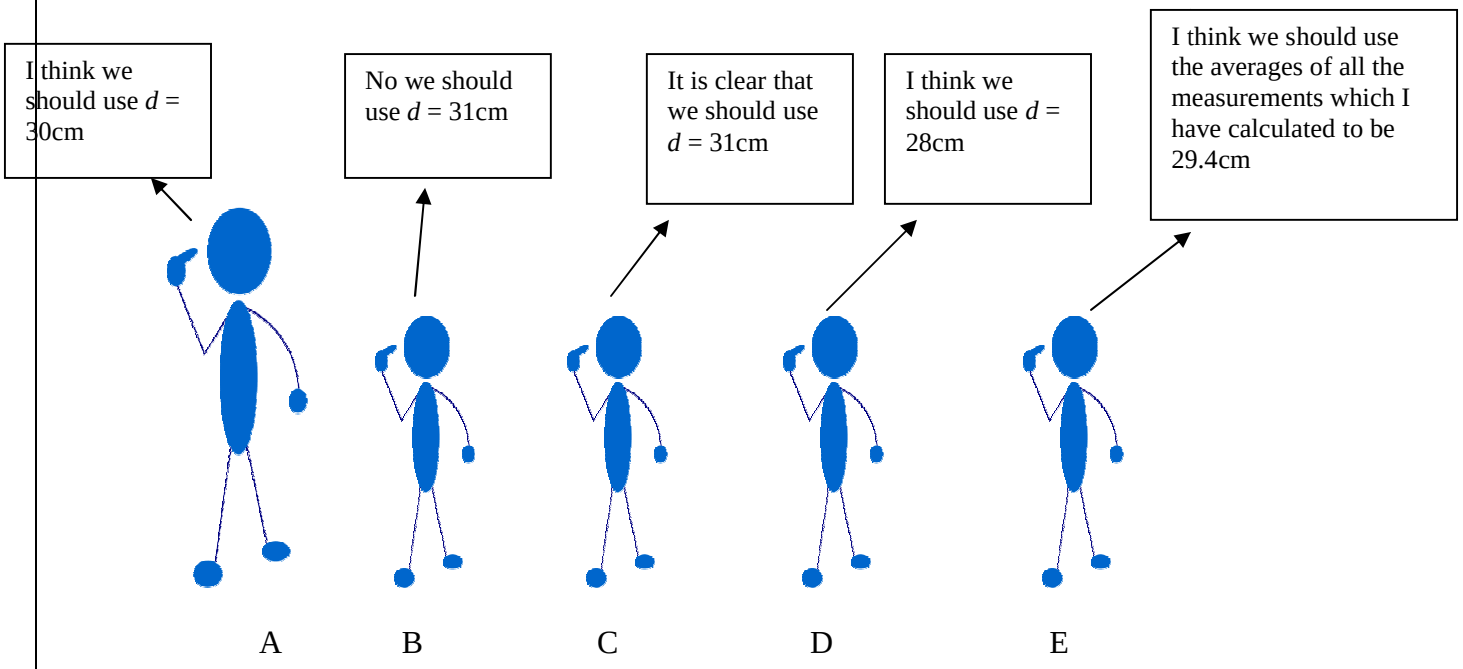
Explain your choice.

_____
_____
_____
_____
_____
_____

Probe 4

The student's continue to release the ball down the slope at a height h = 10cm. Their first five releases are:

Release	d (cm)
1	30
2	28
3	31
4	30



With whom do you most agree? (Circle ONE):

A	B	C	D	E

Explain your choice.

_____
_____
_____
_____
_____

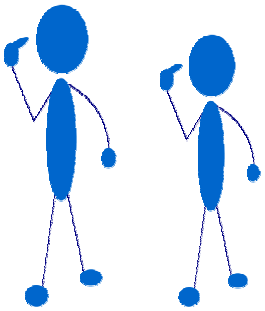
Probe 5

Another group of students have decided to calculate the average of all their measurements of *d* for *h* = 10cm. Their results for six releases are:

Release	*d* (cm)
1	35
2	28
3	31
4	50
5	31
6	30

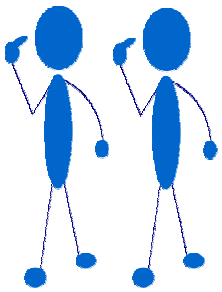
The students then discuss what to write down for the average *d*.

All we need to do is add all our measurements and then divide by 6.



A

No we should ignore *d* = 80cm and then add the rest and divide by 5.



B

With whom do you most agree? (Circle ONE):

A	B

Explain your choice.

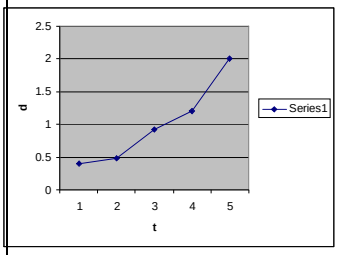
_____

_____

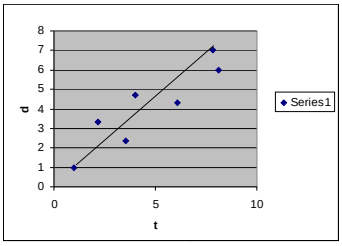
_____

Probe 6

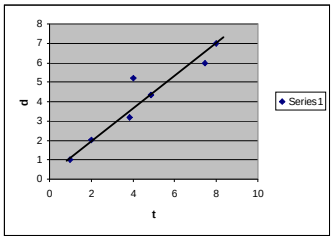
A group of four students collect date at different heights and use it to plot a straight line graph. Each student uses the same data to plot a graph. The four graphs are shown below and the students discuss which line is the most appropriate.



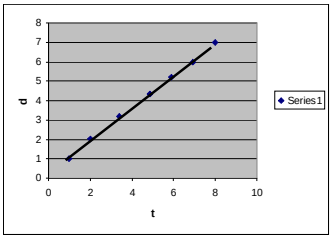
A



B

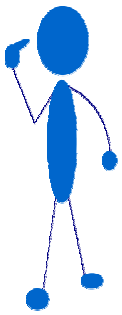


C



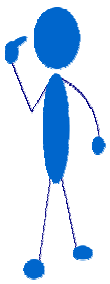
D

I think that my graph is the best.



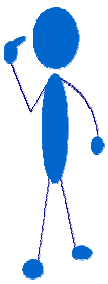
A

I think that my graph is the best.



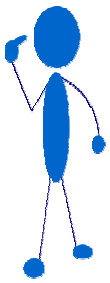
B

I think that my graph is the best.



C

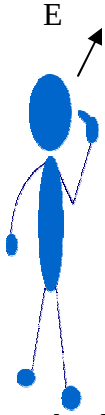
I think that my graph is the best.

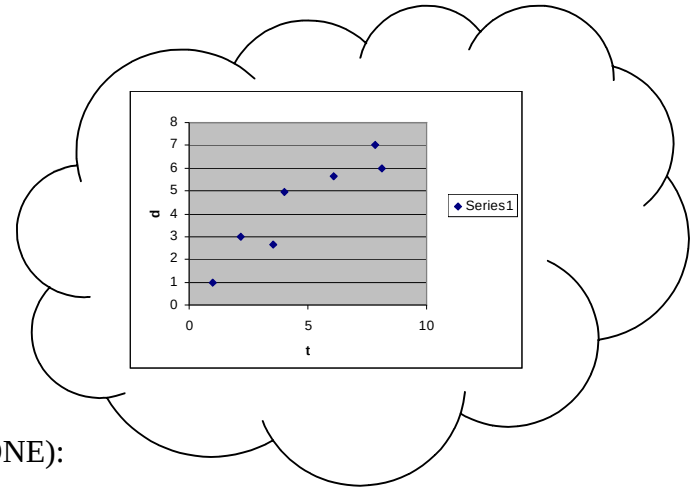


D

E

I don't think any of the graphs is the best. I'll show you what to do.





With whom do you most agree? (Circle ONE):

A	B	C	D	E

Explain your choice.

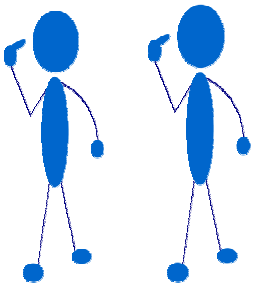
_____
_____
_____
_____
_____

Probe 7

Two groups of students compare their results for d obtained by releasing the ball at h = 10cm. Their results for five releases are shown below.

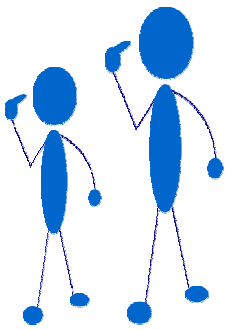
	Group A	Group B
Release	d (cm)	d(cm)
1	36	37
2	50	32
3	31	25
4	35	31
5	33	35
Average	34	34

Our results are better. They are all between 31cm and 37cm. Yours are spread between 50 and 31cm



A

Our results are just as good as yours. Our average is the same as yours. We both got 34 for d.



B

With whom do you most agree? (Circle ONE):

A	B

Explain your choice.

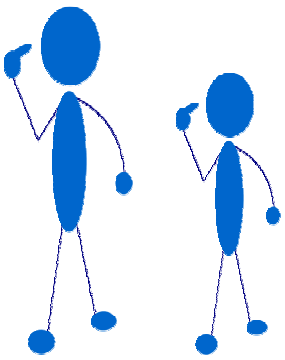
Probe 8

Two other groups of students compare their results for *d* obtained by releasing the ball at *h* = 10cm. Their results for five releases are shown below.

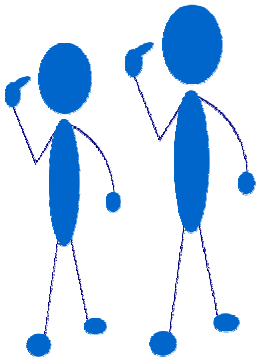
	Group A	Group B
Release	*d* (cm)	*d*(cm)
1	30	28
2	25	30
3	28	25
4	24	26
5	30	29
Average	27	28

Our results agrees with yours

No, your results don't agree with ours.



A



B

With whom do you most agree? (Circle ONE):

A	B

Explain your choice.

_____

_____

_____

APPENDIX 3

ALPHANUMERIC CODING SCHEME. (Adapted from Lubben et al. 2000)

The coding scheme works as follows: Letter –letter- number- number

1. The first letter was assigned for Point (P) and Set(S) reasoning/action to each response category. Where the responses or individual response could not be clearly categorized as point or set, a (M) was assigned that designated Mixed reasoning.
2. Where no reason was given or the response was uncodeable, a (U) was assigned unless the choice itself indicates Point action/reason.
3. The second letter indicates the choice of the student, e.g. an (A) was assigned if the student chose A,etc. No response was assigned an (U).
4. For the UR probe, letters were assigned according to the type of answer given, e.g. using all readings for the average calculation was categorized as an (A).
5. The first and second numbers were assigned in a logical manner, e.g. all responses including an average calculation in the RD probe was assigned a 2 as the first number and a second number according to the different category of responses within this group.

PROBE 1: PURPOSES OF DOING REPEATS MORE THAN ONCE (DISTANCE) RD

UN00 No response
UU00 Uncodeable

I agree with A because ……

UA00 No reason
UA01 Uncodeable reason
MA10 You need to practice
MA11 Practice to minimize/take into account outside factors.
MA12 Practice to eliminate "errors"/mistakes/discrepancies
MA15 Practice will get a more accurate/better measurement.
SA20 More measurements are needed to take an average/mean
SA21 Get a more accurate/reliable average/mean – take into account outside factors.
SA22 Get a more accurate/reliable average/mean – reduce effect of "errors"/mistakes
SA23 Get average and a better/narrower spread/uncertainty
SA24 To get an average to get closer to the true value.
SA25 Get an average to be more accurate/get a more accurate answer
PA30 Get the recurring/same/correct answer-be confident of answer
PA32 Confirm recurring reading –eliminate "errors"/mistakes
PA35 Confirm recurring reading-check accuracy
MA40 Need a variety of/different results
MA60 Have to do it several times (no reason provided)
MA61 Get a more accurate/reliable result-take into account outside factors
MA62 Get a more accurate/reliable result-reduce effect of "errors"
MA64 Get closer to the true value
MA65 To be more accurate/get a more accurate answer
SA70 To determine the spread/uncertainty
SA74 To determine the spread/uncertainty to get closer to the truth
SA75 To determine a better/narrower spread/uncertainty
MA80 Decide to do more measurements if variation
MA81 Decide to take recurring value or an average if variation

I agree with B because …..

PB00 No reason
PB01 Uncodeable
PB30 Repeats will give the same result
PB31 Repeats will give the same result if outside factors are the same
PB40 Repeats will give different results which is confusing/pointless
PB50 Repeats are a waste of time/resources

I agree with C because …..

UC00	No reason
UC01	Uncodeable
PC30	Get the recurring/same answer
PC32	Check that no errors was made in obtaining (recurring/same) measurement
PC35	Check the accuracy of the (recurring/same) measurement
MC40	Need a variety of/different results
PC50	Many repeats are a waste of time/resources
MC80	Decide to take more measurements if variation in second reading
MC81	Decide to take more measurement if variation and calculate average.

PROBE 2: PURPOSES OF DOING REPEATS MORE THAN ONCE (RDA)

I agree with A because…..

PA01	Uncodeable reason
PA40	Repeating will give a different result again, no point in repeating
PA45	No point in repeating-accuracy is acceptable (only 2%deviation)
PA 50	repeating is waste of time/resource
SA20	take average

I agree with B because…..

UB01	Uncodeable reason
MB10	You need to practice
MB15	Practice will get a more accurate/better measurement
SB20	3 measurements are sufficient to take an average/mean
SB21	Get a more accurate/reliable average/mean – take into account outside factor
SB22	Get a more accurate/reliable average/mean-reduce effect of error/mistakes
SB23	Get average and a better/narrower spread/uncertainty
SB24	To get an average to get closer to the true value
SB25	Get an average to be more accurate/get a more accurate answer
SB28	3 measurements to get an average,if variation,repeat several more times.
PB30	Get the recurring/correct answer-be confident of answer
PB32	Confirm recurring reading-eliminate errors/mistakes
PB35	Confirm recurring reading – check accuracy
MB40	3 is enough:too many different answers are confusing.
PB50	Many repeats is a waste of time
MB60	Have to do it 3 times (no reason provided)
MB62	Get a more accurate/reliable result – reduce effects of errors
MB65	To be more accurate/get a more accurate answer
MB80	Decide to do more measurements if variation
MB81	Decide to take recurring value or an average if variation

I agree with C because…..

UC01	Uncodeable reason
MC10	You need to practice
MC15	Practice will get a more accurate/better measurement
SC20	More measurements are needed to take an average/mean
SC21	Get a more accurate/reliable average/mean – take into account outside factors
SC22	Get a more accurate/reliable average/mean – reduce effects of errors/mistakes
SC23	Get average and a better/narrower spread/uncertainty

SC24	To get an average to get closer to true value
SC25	Get an average to be more accurate/get a more accurate answer
PC30	Get the recurring/same/correct answer – be confident of answer
PC31	Confirm recurring reading – take into account outside factors
PC32	Confirm recurring reading – eliminate errors/ mistakes
PC35	Confirm recurring reading – check accuracy
MC40	Need a variety of/different results
MC60	Have to do it several times (no reason provided)
MC61	Get a more accurate/reliable result – take into account outside factors
MC62	Get a more accurate/reliable average/mean – reduce effects of errors/mistakes
MC64	Get closer to the true value
MC65	To be more accurate/get a more accurate answer
SC75	To determine the spread/uncertainty
MC80	Decide to take recurring reading or take more measurements if variation
MC81	Decide to take recurring reading or an average if variation

PROBE 3: PURPOSES OF DOING REPEATS MORE THAN ONCE (TIME) (RT)

UN00	No response
UU00	Uncodeable

I agree with A because…..

PA00	No reason
PA01	Uncodeable
PA30	Repeats will give the same result
PA31	Repeats will give the same result if outside factors are constant
PA35	Repeats will give then same result if very accurate measuring system is used
PA40	Repeats will give different results which is confusing/pointless
PA50	Repeats are a waste of time/resources

I agree with B because…..

UB00	No reason
UB01	Uncodeable
PB30	Get the recurring/same answer
PB32	Check that no errors was made in obtaining (recurring/same) measurement
PB35	Check the accuracy of the (recurring/same) measurement
MB40	Need a variety of/different results
PB50	Many repeats are a waste of time/resource
SB20	Get an average

I agree with C because…..

UC00	No reason
UC01	Uncodeable reason
MC10	You need to practice
MC11	(practice) to minimize/take into account outside factors
MC12	(practice) to eliminate errors/mistakes/discrepancies
MC15	(Practice will) get a more accurate/better measurement
SC20	More measurements are needed to take an average/mean
SC21	Get a more accurate/reliable average/mean – take into account outside factors
SC22	Get a more accurate/reliable average/mean – reduce effect of errors (in taking time-stop watch)/mistakes
SC23	Get average and a better/narrower spread/uncertainty
SC24	To get an average to get closer to true value
SC25	Get an average to be more accurate/get a more accurate answer
SC28	Eliminate/discard erroneous results – average of results in similar range – accuracy

PC30	Get the recurring/same/correct answer – be confident of answer
PC32	Confirm recurring reading – eliminate errors/ mistakes
PC35	Confirm recurring reading – check accuracy
MC40	Need a variety of/different results
MC41	Need many repeats as will get variation as before
MC45	Repeats are needed to be confident of results
MC60	Have to do it several times (no reason provided)
MC61	Get a more accurate/reliable result – take into account outside factors
MC62	Get a more accurate/reliable average/mean – reduce effects of errors/mistakes (stop watch)
MC63	Repeats are needed to get an approximate answer
MC64	Get closer to the true value
MC65	To be more accurate/get a more accurate answer
MC80	Decide to take recurring reading or take more measurements if variation (due to errors/ext factors)
MC81	Decide to take recurring reading or an average if variation (due to errors/ext factors)
PC	select last reading.

PROBE 4: USING REPEATED MEASUREMENTS (UR)

A:

SA20	Take the average of all readings
SA21	Average to take into account outside factors
SA22	Average to take into account errors/mistakes
SA24	Average to get closer to true value
SA25	Average to be more accurate
SA26	Average is closest to all values
PA20	Take first reading no need for repetition
PA21	Take middle measurement
MA31	More repeats are necessary to decide on best/recurring measurement – average
MA35	You can't choose one measurement – average must be calculated
SA60	More accurate to use average: takes into account all measurements
SA61	No reason to ignore any individual measurement – average includes all
SA62	No large errors/duds – cannot discard any measurement – average includes all
SA64	No experimental result is exact (=true value) – use all data to obtain average
SA70	Average best represents true value as most measurements would fall within range (spread/uncertainty) of the mean
SA71	Average is a good approximation/prediction of subsequent measurements
SA80	Variation in measurements – average is a better solution/answer
SA81	Variation in measurements is small (no large discrepancies) – safe to take average

B:

SB22	Discard most wayward (furthest from average) measurement

C:

SC20	Discard highest and lowest measurements
SC22	Discard highest and lowest measurements as due to experimental error/mistakes

D:

PD30	Take the measurement that recurs most often/appears more than once
MD81	Take the measurement that recurs or the mean/average of all the readings

E:

PE34	Take measurement that is closest to the average
SE25	Average to be more accurate
SE21	Average to take into account outside factors
SE60	Need to take all measurements to take average

PROBE 5: DEALING WITH ANOMALY (AN)

N00	No response
U00	Uncodeable

I agree with A because…..

A00	No explanation
A01	Uncodeable
A10	The average gives the approximate value of *d*
A20	This is how the average is calculated
A25	Including all the measurements gives a truer/more accurate average
A60	All the measurements have been taken into account
A61	Large difference in *d* = 50 caused by different conditions (outside factors) but can not omit.
A62	Cannot prove *d* = 50 is a discrepancy/error – cannot omit
A65	It is more accurate to include all the measurement
A70	Large difference in *d* = 50, but there is always a spread in the measurements
A81	More measurements needed to decide if *d* = 50 is a discrepancy – cannot omit

I agree with Bbecause…..

B00	No explanation
B01	Uncodeable
B21	Large difference in *d* = 50 due to outside factor/s – omit/ignore to get more accurate/reliable/less biased (distorted) average/result
B22	Large difference in *d* = 50 due to error/mistake - omit/ignore to get more accurate/reliable/less biased (distorted) average/result
B25	Large difference in *d* = 50 due to inaccuracy - omit/ignore to get more accurate/reliable/less biased (distorted) average/result
B60	Large difference in *d* = 50 – omit/ignore
B61	Large difference in *d* = 50 due to outside factors- omit/ignore
B62	Large difference in *d* = 50 due to error/mistake – omit/ignore
B65	Large difference in *d* = 50 due to inaccuracy – omit/ignore
B80	*d* = 80 due to experimental error – repeat and use this more realistic measurement to take the average out of 6
B81	More measurements are needed to decide if *d* = 50 is a discrepancy – omit in the absence of additional evidence
B90	Ignoring incorrect measurement will result in a more accurate/better graph

PROBE 6: STRAIGHT LINE GRAPH (SLG)

N00	No response
U00	Not able to code response
P10	I have joined all the points
S11	I have included all the points
P20	I have joined the lowest and highest points
P21	The line goes through the middle point
P22	The line goes through the most number of points
S30	Some points lie above the line, some below the line
S31	The same number of points lie above and below the line
S40	All points are quite close to the line
S41	This gives the smallest uncertainty/smallest sum of squares
S42	The line is the least squares fit to the data
50	This is how we always draw straight lines
60	The line goes through the origin
S61	Best fits all the points and goes through the origin.

PROBE 7: SPREADS OF RESULTS WITH THE SAME AVERAGE (SMDS)

UN00	No response
UU00	Uncodeable

I agree with A because…..

UA00	No reason
UA01	Uncodeable
SA10	Results are closer together/smaller range (spread)/less variation
SA11	Smaller range/spread-results more accurate/reliable because less outside factors
SA12	Smaller range/spread - results more accurate/reliable because less errors/mistakes
SA13	Smaller range/spread – more certain of results
SA14	Smaller range/spread – more certain of/closer to the exact/true distance
SA15	Smaller range/spread – results more accurate/reliable: group more careful/skillful
SA20	There is less deviance from the average
SA21	less deviance from average – results better/more accurate/reliable because less outside factors
SA22	Less deviance from average – results better/more accurate/reliable because less errors/mistakes
SA24	Less deviance from average – results are closer to the truth/exact distance
SA25	Less deviance from average – results more accurate/reliable: group more careful/skillful
MA60	The results are more accurate /reliable
MA61	Results more accurate/reliable because less outside factors (better controlled)
MA62	A had less errors/mistakes than B
SA70	Results have a smaller standard deviation
SA74	Results have smaller standard deviation – greater chance of obtaining average

I agree with B because…..

PB00	No reason
PB01	Uncodeable
PB10	Measurements are more or less the same
PB15	Results/measurements are similar – equally valid
PB20	Most important to get the same average
PB21	Results alike as same average – although different variables/conditions/outside factors caused variation
PB22	Same average most important – compensates for errors/mistakes in indiv. Readings
PB23	Same average most important – range/spread not important

PB25	Same average – equally accurate/individual results equally valid as variation expected
PB40	Variation not important, to repeat many times.
PB60	Variation in results not important
PB65	Accuracy of individual results not under consideration – average important

I agree with C because…..

UC01	Uncodeable reason
MC40	B's results vary more
MC41	B shows greater variation in results which more clearly demonstrates that external factors affects experiments.

PROBE 8: SPREADS OF RESULTS WITH THE DIFFERENT AVERAGE (DMSS)

UN00	No response
UU00	Uncodeable

I agree with A because…..

UA00	No reason
UA01	Uncodeable
PA10	Individual measurements for both sets close together/similar
PA15	Degree of accuracy (difference) insignificant compared to actual reaings
PA20	Small difference between averages
PA21	Small differences between averages: differences due to external factors
PA22	Small differences between averages: differences due to/within experimental errors
PA23	Small differences between averages: differences due to systematic uncertainty of equipment
PA24	Small differences between averages: both close to true value
PA25	Small differences between averages: both groups equally accurate
PA26	Small differences between averages can be ignored as due to minor statistical differences
PA30	Two groups have readings that are identical, otherwise similar (readings,averages)
MA40	Small differences between averages with similar/same ranges/spreads
MA42	Ranges very similar: small error negligible since averages almost equal.
PA43	Difference in average is small/negligible relative to large deviation in readings
MA45	Small difference between averages with similar spreads showing accuracy/reliability for both
PA60	Averages are only estimates – averages agree since approximately equal
PA65	Results are both averages – no large degree of accuracy required
MA70	Averages are similar since the individual results deviate from average randomly
SA71	Uncertainities of averages overlap – agreement depends on range (averages falls within range/spread/uncertainty of other groups result/s)
MA80	If the most wayward measurement is excluded, results will agree reasonably

I agree with B because…..

PB00	No reason
PB01	Uncodeable
PB10	The measurements are not the same
PB15	A/B more accurate since individual results show less deviation in subsequent results
PB20	Averages are different
PB21	Averages are different due to different conditions/external factors
PB22	Averages are different due to experimental errors

PB25	Averages are different – absolute accuracy/identical results is/are required to agree
PB30	A is better – have more individual readings closer to the average
PB31	Averages different, all individual readings are not the same
PB40	Averages are different and individual measurements/ranges are different
PB43	Although difference in averages are small, there is large difference in readings
PB60	They simply don't agree
PB81	Large variation, don't agree

APPENDIX 4

Analysis of Results

PROBE 1,2,3

STD. NO	RD RESPONSE	RDA RESPONSE	RT RESPONSE	P,Q,R,S,U,M
1	PC35	PC35	PC30	P
2	PC32	PB35	PC35	P
3	PB40	PC35	PC35	P
4	PC35	MB14	PB35	Q
5	PC35	PC35	PC35	P
6	PC35	PA40	PA40	P
7	SA22	SB25	MC15	R
8	PB30	PB30	PA30	P
9	PC32	PB32	SC28	Q
10	PB50	SC21	MC15	Q
11	PB40	PA40	SC25	R
12	PC35	SB28	SC20	R
13	PA35	PA45	PC35	P
14	MA15	SB20	PC35	M
15	SA22	PB30	PC30	Q
16	PB31	SB20	PC30	Q
17	PA35	PB30	PC30	P
18	PA35	PC30	PC35	P
19	PA30	PB30	PB30	P
20	SA20	SB20	SC20	S
21	PC35	PA45	PB30	P
22	PA30	PC30	PC30	P
23	SA25	SC25	MC15	R
24	UC01	UB01	UA01	U
25	SA25	MC80	PC32	M
26	PC30	PB35	SC20	Q
27	UB01	UC01	UC01	U
28	PC30	MB60	MC15	M
29	UN00	UN00	UC00	U
30	PB40	PA40	MC80	Q
31	MA61	MC80	MC80	M
32	PC30	MC40	SC28	M
33	PC35	MB40	PC30	Q
34	UC01	UA01	UB01	U
35	PC35	SB25	SC20	R
36	PC30	SB25	SC25	R
37	PC30	SC24	PB30	Q
38	SA22	SB28	SC20	S
39	MA15	SB25	SC20	R
40	MA15	PC35	SC20	M
41	PA30	PB35	SC20	Q

42	PB50	PA50	PC30	P
43	PC32	PB35	SC20	Q
44	PC30	PB30	PB35	P
45	PC30	PA40	SC20	Q
46	PC30	PB30	SC20	Q
47	PC35	MB65	PB30	Q
48	PC30	PB30	SC20	Q
49	UA01	UC01	UC01	U
50	UA01	UC01	UC01	U
51	UN00	UN00	UCOO	U
52	PB30	PB30	PC35	P
53	SA20	SB20	SB20	S
54	MA60	MB60	MB40	M
55	UN00	UN00	UN00	U
56	PC35	PC35	PC35	P
57	PC35	PB32	PA30	P
58	SA22	SB20	SC25	S
59	SA22	SB25	SC21	S
60	PC35	PC35	PC35	P
61	UC00	UC00	UC00	U
62	PB40	PA40	PC35	P
63	MA15	MC15	MC15	M
64	PB31	PB30	PC30	P
65	MA61	MC80	MC80	M
66	PC50	PA50	UC00	Q
67	PC35	SB25	SC20	R
68	UB00	UA00	UC00	U

ANALYSIS OF AN PROBE 5

STD. NO	AN RESPONSE	CATEGORY	STD. NO	
1	**B60**	AN4	39	A70
2	**B60**	AN4	40	A20
3	A25	AN1	41	A61
4	**B60**	AN4	42	B60
5	**B60**	AN4	43	A20
6	**B60**	AN4	44	B60
7	A61	AN2	45	A20
8	A25	AN1	46	B60
9	**B60**	AN4	47	B60
10	B61	AN3	48	B62
11	**B60**	AN4	49	A00
12	**B60**	AN4	50	B00
13	B80	AN3	51	B61
14	A25	AN1	52	A20
15	A25	AN1	53	B60
16	B61	AN4	54	A70
17	A25	AN1	55	N00
18	A25	AN1	56	B60
19	**B60**	AN4	57	B62

20	**B60**	AN4	58	B60
21	**B60**	AN4	59	B62
22	**B60**	AN4	60	N00
23	**B60**	AN4	61	A70
24	B00	AN3	62	N00
25	A20	AN1	63	B62
26	**B60**	AN4	64	A20
27	**B01**	AN4	65	A20
28	B60	AN4	66	B61
29	N00		67	A20
30	**B60**	AN4	68	B00
31	**B60**	AN4		
32	A20	AN1		
33	**B60**	AN4		
34	**B60**	AN4		
35	A20	AN1		
36	A20	AN1		
37	B62	AN3		
38	B62	AN3		

ANALYSIS OF PROBES UR AND SLG

STD. NO	UR PROBE	SLG PROBE	P/S/M	STD. NO	UR PROBE	SLG PROBE	P/S/M
1	PD30	P21	P	35	SE60	S40	S
2	PD30	P20	P	36	SE60	N00	S
3	PA20	P20	P	37	SE60	S40	S
4	SE60	P22	M	38	SE60	N00	S
5	SE60	P22	M	39	SE60	S40	S
6	PD30	P20	P	40	SE60	S61	S
7	PC00	P20	P	41	SE60	S40	S
8	SE60	S40	S	42	PD30	S61	M
9	SE60	U00	S	43	SE60	S61	S
10	SE60	P22	M	44	SE60	S61	S
11	SE60	S40	S	45	PD30	P10	P
12	SE60	P10	M	46	SE60	S61	S
13	SE60	N00	S	47	PD30	P20	P
14	SE21	S40	S	48	SE60	S40	S
15	SE60	S40	S	49	U00	UN0	U
16	SE60	S40	S	50	U00	UN0	U
17	MA30	S40	M	51	UN0	UN0	U
18	SE60	S40	S	52	SE60	S40	S
19	SE60	N00	S	53	PA20	P20	P
20	SE60	P10	M	54	PA20	P22	P
21	PA21	P10	P	55	UN0	UN0	U
22	SE60	N00	S	56	SA25	S61	S
23	SA25	S40	S	57	SA25	S40	S
24	U00	UN0		58	SE60	S40	S
25	SA26	S40	S	59	SE60	S40	S

26	SE21	S40	S	60	A21	S40	M
27	U00	UN0		61	UN0	UN0	U
28	PD30	P22	P	62	PD30	P20	P
29	UN00	NOO		63	SE60	S31	S
30	SE60	NOO	S	64	SE60	S40	S
31	SE60	60	S	65	U00	N00	U
32	SE60	S30	S	66	U00	50	U
33	SE60	S61	S	67	SE60	S61	S
34	U00	UN0	S	68	U00	UN0	U

ANALYSIS OF SMDS AND DMSS PROBES

STD. NO	SMDS	DMSS	I/N/M/U	STD. NO	SMDS	DMSS	I/N/M/U
1	PB20	PA20	I	35	SA11	PA20	M
2	PB20	PB10	I	36	MA61	PA30	M
3	SA10	PB20	M	37	PB20	PB10	I
4	PB20	PB25	I	38	PB20	PA20	I
5	PB20	PB20	I	39	SA10	PB10	M
6	PB23	PA20	I	40	SA10	PB30	M
7	SA11	PB20	M	41	SA11	81	M
8	SA10	MA45	M	42	PB20	PA22	I
9	PB20	PB20	I	43	MA62	MA45	M
10	PB20	PB209	I	44	PB20	PA20	I
11	PB20	PA20	I	45	SA10	PA20	M
12	PB20	PA20	I	46	PB20	PB20	I
13	PB20	PA25	I	47	PB20	PB20	I
14	SA11	PA25	M	48	PB20	PB20	I
15	SA12	PB22	M	49	UA00	UA00	U
16	PB60	PB31	I	50	UB01	UA00	U
17	SA13	PB43	M	51	UN00	UN00	U
18	SA13	PB40	M	52	SA10	PA20	M
19	PB20	PB10	I	53	SA10	PA30	M
20	PB20	PB15	I	54	PB20	PB20	I
21	PB20	PA25	I	55	UN00	UN00	U
22	PB20	PA20	I	56	PB20	PA20	I
23	PB60	PA21	I	57	PB20	PB20	I
24	UB00	UB01	U	58	SA11	PA25	M
25	SA15	PB20	M	59	PB20	PB10	I
26	SA20	PA20	M	60	SA15	PA20	M
27	UB01	UA01	U	61	UN00	UN00	U
28	PB00	PB10	I	62	PB21	PB20	I
29	UN00	UN00	U	63	PB21	PA20	I
30	PB20	PA25	I	64	PB65	UOO	M
31	PB20	PA25	I	65	PB20	UOO	M
32	SA25	PA22	M	66	PB20	PA21	I
33	PB20	PA20	I	67	PB20	PB10	I
34	UB01	UA01	U	68	UB01	UB01	U

For Official Use	
Ref. No.	

GAUTENG DEPARTMENT OF EDUCATION

RESEARCH REQUEST FORM

REQUEST TO CONDUCT RESEARCH IN INSTITUTIONS AND/OR OFFICES OF THE GAUTENG DEPARTMENT OF EDUCATION

1. PARTICULARS OF THE RESEARCHER

1.1	Details of the Researcher
Surname and Initials:	SHAIKH .S.
First Name/s:	SAFURA
Title (Prof / Dr / Mr / Mrs / Ms):	MS
Student Number (if relevant):	02104436
ID Number:	680122 0759 083
Gender (Male/Female):	FEMALE

1.2	Private Contact Details
Home Address	*Postal Address (if different)*
1355 ANDER ROAD	P.O.BOX 4204
BERGBRON, ROODEPOORT	CRESTA 2118
	RANDBURG.
Postal Code:	*Postal Code:* 2118

2. PURPOSE & DETAILS OF THE PROPOSED RESEARCH

2.1	Purpose of the Research (Place cross where appropriate)
Undergraduate Study - Self	
Postgraduate Study - Self	X
Post-Doctoral Study	
Private Company/Agency – Commissioned by Provincial and/or National Government Department/s	
Private Research by Independent Researcher	
Non-Governmental Organisation	
National Department of Education Commissioned Study	
Commissions and Committees	
Independent Research Agency	
Statutory Research Agency	
Independent Study by Higher Education Institution	

2.2	If Post-Graduate Study – Please indicate by placing a "X" in the appropriate column	
Honours	*Masters*	*Doctorate*
	X	

2.3	Full title of Thesis / Dissertation / Research Project
GENDER DIFFERENCES IN LEARNERS' IDEAS ABOUT MEASUREMENT.	

2.4	Value of the Research to Education (Attach Research Proposal)
SEE ATTACHED DOCUMENT	

2.5	Student and Postgraduate Enrolment Particulars (if applicable)
Name of institution where enrolled:	WITS
Degree / Qualification:	MSC (SCIENCE EDUCATION)
Faculty:	
Department:	
Name of Supervisor / Promoter:	MR. MIKE STANTON

2.6	Employer (where applicable)
Name of Organisation/School:	ROOSEVELT HIGH SCHOOL
Position in Organisation:	EDUCATOR
Head of Organisation:	MR TONY LEROUX
Street Address:	THIBAULT STREET ROOSEVELT PARK
Postal Code:	2129
Telephone Number (Code + Ext):	(011) 782 4937
Fax Number:	(011) 888 4895
E-mail:	rhs@icon.co.za

2.7	PERSAL Number (where applicable)

1	8	9	7	2	6	2	5

3. PROPOSED RESEARCH METHOD/S

(Please indicate by placing a cross in the appropriate block whether the following modes would be adopted)

3.1 ***Questionnaire/s (If Yes, supply copies of each to be used)***

YES	X	NO	

3.2 ***Interview/s (If Yes, provide copies of each schedule)***

YES		NO	

3.3 ***Use of official documents***

YES		NO	X
If Yes, please specify the document/s:			

3.4 ***Workshop/s / Group Discussions. (If Yes, Supply details)***

YES		NO	X

3.5 ***Standardised Tests (e.g. Psychometric Tests)***

YES		NO	X
If Yes, please specify the test/s to be used and provide a copy/ies			

4. RESEARCH PROCESSES

4.1 ***Types of Institutions.*** **(Please indicate by placing a cross alongside all types of institutions to be researched).**

INSTITUTIONS	Mark with "X" here
Primary Schools	
Secondary Schools	X
Technical Schools	
ABET Centres	
ECD Sites	
LSEN Schools	
Further Education & Training Institutions	
Other	

4.2 ***Number of institution/s involved in the study.*** **(Kindly place a sum and the total in the spaces provided).**

Type of Institution	Total
Primary Schools	
Secondary Schools	2
Technical Schools	
ABET Centres	
ECD Sites	
LSEN Schools	
Further Education & Training Institutions	
Other	
GRAND TOTAL	2

4.6 ***Number of educators/officials involved in the study.*** **(Please indicate the number in the relevant column).**

Type of staff	Educators	HODs	Deputy Principals	Principal	Lecturers	Office Based Officials
Number						

4.7 ***Are the participants to be involved in groups or individually?*** **Please mark with an "X".**

Participation	
Groups	
Individually	X

4.8 ***Average period of time each participant will be involved in the test or any other research activity*** **(Please indicate time in minutes)**

Participant/s	Activity	Time
		45 mins

4.9 ***Time of day that you propose to conduct your research.*** **Please mark with an "X".**

School Hours	During Break	After School Hours
		X

4.10 ***School term/s during which the research would be undertaken.*** **Please mark with an "X".**

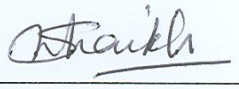
First Term	Second Term	Third Term
		X

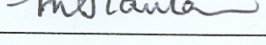
4.3 ***Name/s of institutions to be researched.*** **(Please complete on a separate sheet and append if space is deemed insufficient).**

Name/s of Institution/s
ROOSEVELT HIGH SCHOOL
GREENSIDE HIGH SCHOOL.

4.4 ***District/s where the study is to be conducted.*** **(Please mark with an "X").**

District	
Johannesburg East	
Johannesburg South	
Johannesburg West	
Johannesburg North	X
Gauteng North	
Gauteng West	
Tshwane North	
Tshwane South	
Ekhuruleni East	

DECLARATION BY THE RESEARCHER	
1. *I declare that all statements made by myself in this application are true and accurate.* 2. *I have read and fully understand all the conditions associated with the granting of approval to conduct research within the GDE, as outlined in the GDE Research Briefing Document, and undertake to abide by them.* 3. *Should I fail to adhere to any of the approval conditions set out by the GDE, I would be in breach of the agreement reached with the organisation, and all privileges associated with the granting of approval to conduct research, would fall away.*	
Signature:	
Date:	13/06/05.

DECLARATION BY SUPERVISOR / PROMOTER / LECTURER	
I declare that: - ***1. The applicant is enrolled at the institution / employed by the organisation to which the undersigned is attached.*** ***2. The overall research processes meet the criteria of:*** • ***Educational Accountability*** • ***Proper Research Design*** • ***Sensitivity towards Participants*** • ***Correct Content and Terminology*** • ***Acceptable Grammar*** • ***Absence of Non-essential / Superfluous items***	
Surname:	STANTON
First Name/s:	Michael
Institution / Organisation:	University of Witwatersrand
Faculty:	Science
Department:	Physics
Telephone:	(011) 717-6867
Fax:	(011) 717-6879
Cell:	—
E-mail:	stanton@physics.wits.ac.za
Signature:	
Date:	13 June 2005.

N.B. This form (and all other relevant documentation where available) may be completed and forwarded electronically to Ebrahim Farista (ebrahimf@gpg.gov.za) or Nomvula Ubisi (nomvulau@gpg.gov.za). The last 2 pages of this document must however contain the original signatures of both the researcher and his/her supervisor or promoter. These pages may therefore be faxed or hand delivered. Please mark fax - For Attention: Ebrahim Farista at 011 355 0512 (fax) or hand deliver (in closed envelope) to Ebrahim Farista (Room 911) or Nomvula Ubisi (Room 910), 111 Commissioner Street, Johannesburg.

Appendix 6

C1 APPENDIX 3

A, its a sensible suggestion. They can then see whether the readings are similar or different. Then what would u do if they are diff?

SA00

NM UA00 AU01 (P).

DK UA01 //

Question 2

C - the must do the experiment several time until they get the same result

~~SE~~ PC30

Question 3

D - because it is the only result that they found twice in five attempt

PD30

B B60 Nm

Because the 588 is for off the other results and therefore there was something wrong.

$B60 B60 (P)

D B60

Q4

B. Three will give the right answer. If done correctly

PB13

Q6

A. The end average is at by two therefore it comes down to more or less the same thing.

MA40

Q.9 B

It passes through the coordinates that will be the average of all the points ie. It passes through middle of points.

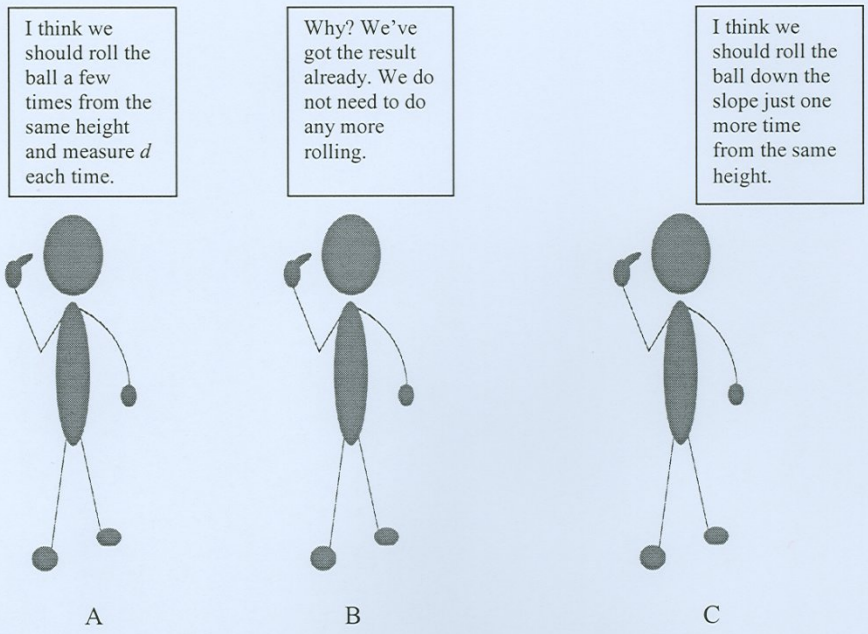
PBLX

26

Probe 1

The students work in groups on the experiment. Their first task is to determine d when h=10cm. One group releases the ball down the slope at height h=10cm and, using a meter stick, they measure d to be 30cm.

The following discussion takes place:



With whom do you most agree? (Circle ONE):

A	B	(C)

Explain your choice.

I choose C because that student wants to make sure one more time to be exact with his result. B didn't want to do it again and I think A wants to do it too many times

PC 30

90

26

Probe 2

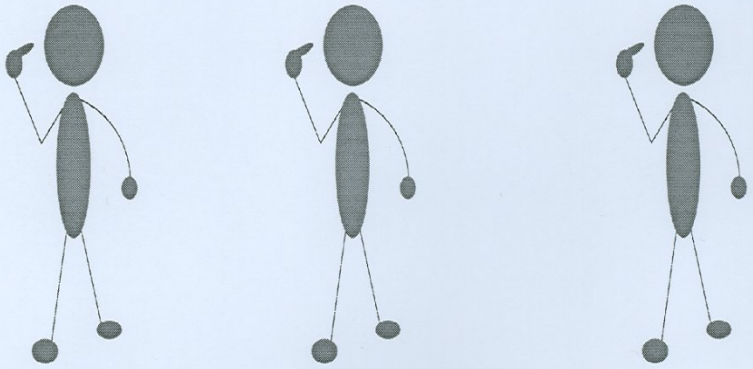
The group of students decide to release the ball again from h = 10cm. This time they measured d = 28cm.

First release: h=10cm d=30cm

Second release : h=10cm d=28cm

The following discussion takes place between the students.

We know enough, we don't need to repeat the measurement again.	We need to release the ball just one more time	Three releases will not be enough. We should release the ball several more times.



A B C

With whom do you most agree? (Circle ONE):

A (B) (C)

Explain your choice.

C is the reasonable one because he is trying to say that if their next measurement is different figure, then they should do it for more times. B will not be suitable because the next measurement could be a different figure. A is not trying to get the exact distance, he/she maybe just wants to estimate and get done with the experiment.

PC 35

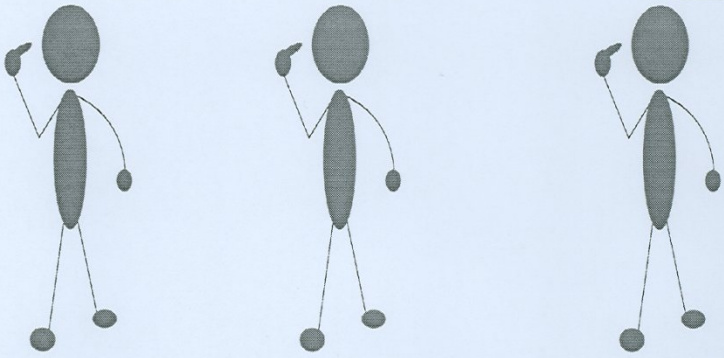
91

26

Probe 3

In order to calculate the speed with which the ball rolls down the ramp, the students are given a stopwatch and are asked to measure the time that the ball takes to stop once it is released from h = 10cm. They discuss what to do.

We can roll the ball once from h = 10cm and measure the time. Once is enough.	Let's roll the ball twice from the height h = 10cm and measure the time for each case.	I think we should release the ball more than twice from h =10cm and measure the time in each case.



A B C

With whom do you most agree? (Circle ONE):

A	B	(C)

Explain your choice.

It's best to do the measurment at least over three times and if they don't ~~agree~~ look the same take the average of ~~the~~ it except the ones which are way off).

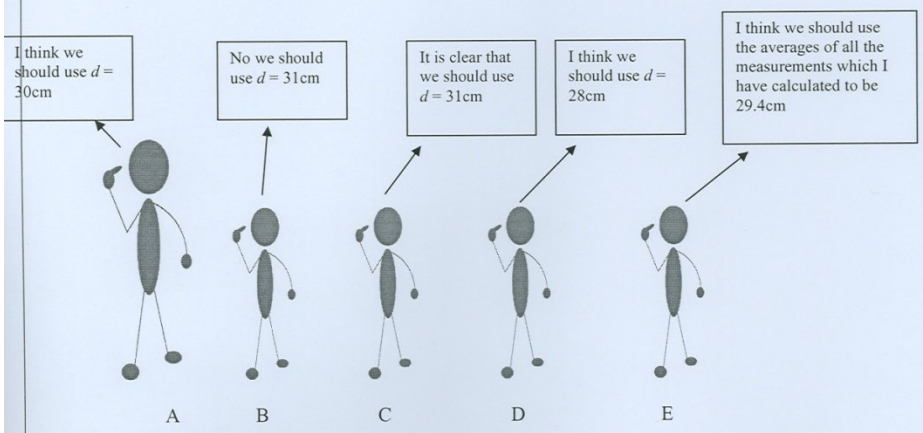
SC20

26

Probe 4

The student's continue to release the ball down the slope at a height h = 10cm. Their first five releases are:

Release	d (cm)
1	30
2	28
3	31
4	28
5	30



With whom do you most agree? (Circle ONE):

A | B | C | D | (E)

Explain your choice.

If we take the average, we take into consideration, all the measurements, even if we got 58 cm. twice, it could mean that it is another distance and not 58 cm, so I think the average of all our results.

SE 21

93

26

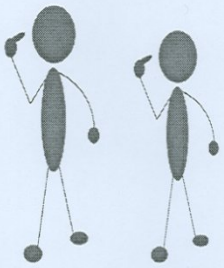
Probe 5

Another group of students have decided to calculate the average of all their measurements of d for h = 10cm. Their results for six releases are:

Release	d (cm)
1	35
2	28
3	31
4	50
5	31
6	30

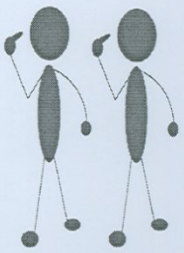
The students then discuss what to write down for the average d.

All we need to do is add all our measurements and then divide by 6.



A

No we should ignore d = 80cm and then add the rest and divide by 5.



B

With whom do you most agree? (Circle ONE):

A	(B)

Explain your choice.

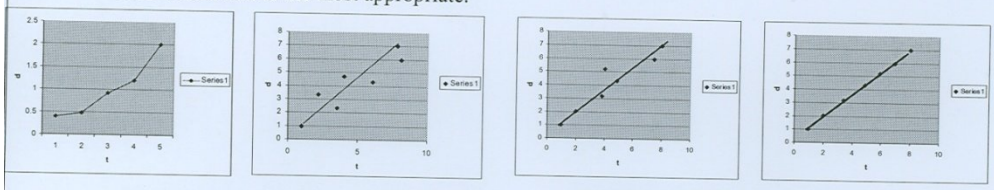
The 50 cm seems way off compared to the others, so I think we can cancel out that one, add the rest and divide by five

B (6)

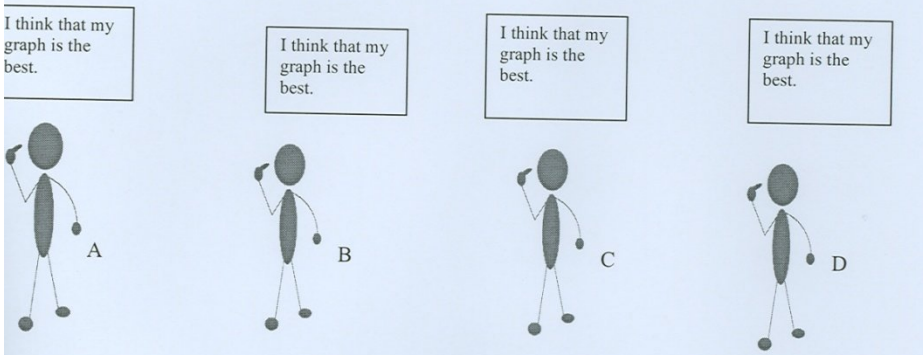
94

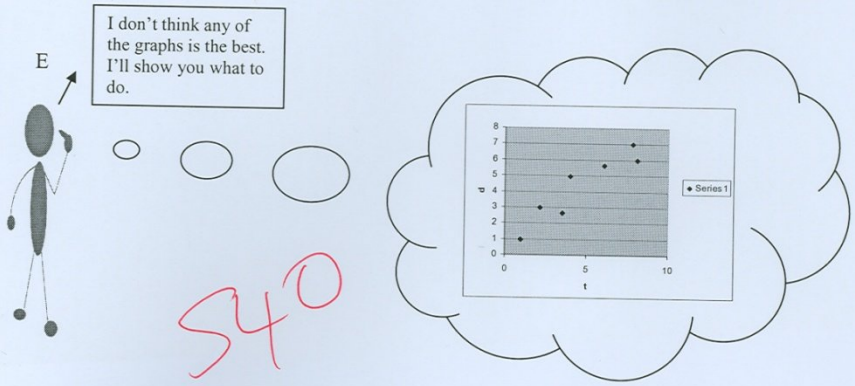
Probe 6

A group of four students collect date at different heights and use it to plot a straight line graph. Each student uses the same data to plot a graph. The four graphs are shown below and the students discuss which line is the most appropriate.



A B C D





54

95

With whom do you most agree? (Circle ONE):

A	B	C	D	E

Explain your choice.

C shows the average of the graph and is used to prove that $E = \frac{1}{2}$ and it directly proportional to each other (As the distance increases so does the time) all Points are close.

84

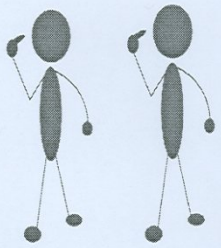
Probe 7

Two groups of students compare their results for d obtained by releasing the ball at h = 10cm. Their results for five releases are shown below.

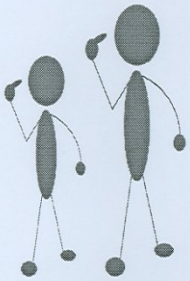
Release	Group A d (cm)	Group B d(cm)
1	37	36
2	32	50
3	31	25
4	35	31
5	33	35
Average	34	34

Our results are better. They are all between 31cm and 37cm. Yours are spread between 50 and 31cm

Our results are just as good as yours. Our average is the same as yours. We both got 34 for d.



A



B

With whom do you most agree? (Circle ONE):

(A)	B

Explain your choice.

It is closer to the average than the other group. The B groups measurements seemed way off compared to the others but got the same average. eg the 90cm

SA 20

97

|26|

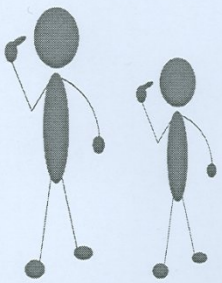
Probe 8

Two other groups of students compare their results for d obtained by releasing the ball at h = 10cm. Their results for five releases are shown below.

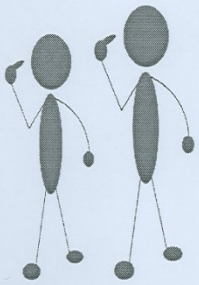
	Group A	Group B
Release	d (cm)	d(cm)
1	30	28
2	25	30
3	28	25
4	24	26
5	30	29
Average	27	28

Our results agrees with yours

No, your results don't agree with ours.



A



B

With whom do you most agree? (Circle ONE):

(A)	B

Explain your choice.

Even if they don't have the same average, they were very close

PA 20