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**The relationship between views of
the nature of science and views of
the nature of scientific measurement**

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Abstract

This study builds on the work started by a collaboration between researchers at the University of Cape Town, South Africa, and the University of York, UK, which focused on undergraduate physics students' understanding of measurement and uncertainty. The work led to the development of a paradigmatic model which has been found to be useful for classifying students' views on measurement during experimental work. In brief, in the "set" paradigm the ensemble of data is modelled by theoretical constructs from which a "best estimate" and the degree of dispersion (an interval) are reported. However, the majority of students who arrive at university operate within the "point paradigm". They subscribe to the notion that a perfect measurement is one which has no uncertainty associated with it. For many students, therefore, the ideal is to perform a single "correct" measurement with the utmost care. When presented with data that are dispersed, they often attempt to choose the "correct" value (for example the recurring value) from amongst the values in the ensemble.

The present work explored the relationship between students' views on the nature of science (NOS) and the nature of scientific measurement. Modifying and supplementing existing diagnostic items in both areas of measurement and nature of science, the VASM (Views About Scientific Measurement) questionnaire was developed, piloted and administered to 179 first year physics students at the University of Cape Town. An analysis of the responses resulted in four profiles of students' views on the nature of science. It also revealed that students who view measurement according to the point paradigm generally have an objective view about science, perceive the purpose of scientific experiment to prove a phenomenon to be correct and use the 'scientific method' to get a predicted answer in order to be consistent and successful in the scientific endeavour. Set paradigm students acknowledge the importance of human inference in science and scientific experiment is considered as a tool to understand the behaviour of nature. The consequences of this work for the teaching and learning of physics at a tertiary level are discussed.

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1. Introduction

The understanding of science can be considered in three groups: science content such as facts, ideas, concepts, laws and theories; the methods and processes used for the acquisition and construction of scientific knowledge through experimental works; and the role and importance of the society within the field of science (Millar, 1996). Of these three categories, the process of “doing science” may be regarded as of utmost importance in scientific activities and thus forms an integral aspect of most science curricula at secondary and tertiary level. It has been argued that “laboratory activities have long had a distinctive and central role in the science curriculum, and that science educators have suggested that many benefits accrue from engaging students in science laboratory activities” (Lunetta, 1998, p. 249).

Before designing experimental activities, either for school or university students, the objectives and intended outcomes of the task must first be considered. What students actually take away from the task is influenced by both the teachers’ and students’ views of science and learning (Tiberghien *et al.*, 2001). According to Gott and Duggan (1996), when laboratory work was first introduced, it was executed solely by science teachers as illustrations of aspects of the theories which students had studied during lectures. Later on, it was thought that students best developed their understanding by being engaged in the practical task themselves. Furthermore, it may be argued that by having hands-on experience with “doing” science, students will develop an understanding about the nature of science (Hodson, 1996). They are also expected to comprehend the different aspects of practical work: to have some knowledge about the conceptual aspect of the system under

investigation and the skills needed to handle the laboratory instruments required for that particular experiment. An understanding of measurement is also needed: what constitutes reliable experimental data; how are data observed, evaluated, interpreted, related to scientific claims; how is a theory related to its experimental evidence for the construction of a conclusion (Lubben and Millar, 1996; Ryder and Leach, 1999). By mastering the different stages of the measurement phase of a laboratory task, and recognizing the various mechanisms involved in data handling, students can develop an understanding of the complexity of science and the scientific endeavour (Leach, 1999).

Gott and Duggan (1996) have summarised the main aims of laboratory work in the context of physics, as shown in Table 1.

Table 1: *The aims of physics laboratory work (Gott and Duggan, 1996, p. 792).*

Aims	Description
1. Motivational aspects linked to the promotion of interest and social skills.	To stimulate and sustain curiosity and an interest in and an enjoyment of physics and its application; to promote interest in and an awareness, and as far as possible an understanding, of the social, and economic and environmental implications of physics; to foster relevant communication skills and the ability to work with others.
2. The application of substantive knowledge.	To encourage students to apply, qualitatively and quantitatively, their knowledge and understanding of physical principles to familiar and unfamiliar situations.
3. The development of experimental skills.	To develop the skills of observation, experimentation (including testing of predictions), the processing and interpretation of data (including evaluation of evidence) and the formulation of generalisations and models; to ensure that students can follow instructions and do comply with safety procedures.

However, the majority of traditional laboratory tasks follow a common (“recipe-type”) format. They typically begin with an aim of the experiment, the procedures to be followed in order to prove a theory, and instructions on which measurements are to be made, thus guiding the students towards the expected conclusion (Hart *et al.*, 2000). Surveys of students’ opinions about the usefulness and purpose of laboratory tasks report the following three findings. Firstly, if the purpose of a recipe-type laboratory task is to prove a theory, then the whole process is seen as a waste of time since the expected or required

result is already known (Lippmann, 2003). Other students find practical work an opportunity to have hands on experience with the experiment which helps them to memorize the theory, or the “scientific truths” as they see the phenomenon taking place (Tsai, 1998). The laboratory session is regarded as a process for replicating the behaviour of a phenomenon in order to acquire the “correct answer” (Leach *et al.*, 1997). Thirdly, other students acknowledge that their main concern is to simply complete the task assigned to them although they have no idea why they are engaged in practical work (Hart *et al.*, 2000).

From the students’ unfavourable responses, it is clear that the aims of practical work, mainly, the “development of experimental skills” (Gott and Duggan, 1996), are often not achieved by traditional laboratory tasks. There is evidence that although students are familiar and adept in experimental work, many of them cannot understand, interpret and evaluate their data (Séré *et al.*, 1993; Coelho and Séré, 1998; Buffler *et al.*, 2001) and do not appreciate the role of theoretical models in data analysis (Ryder and Leach, 2000). Hence, new laboratory courses which emphasize the skills and processes leading to the understanding of measurement should be developed and laboratory tasks should be designed to be more open-ended.

According to Hodson (1998), recipe type laboratory work has the possibility of developing inappropriate scientific epistemological concepts in students. They may come to believe that science provides the “right” answer and that infallible, genuine scientific knowledge is discovered by making use of the scientific method to conduct experiments and gather objective data. This leads to the idea that there is a method of doing science which must be adhered to with the result that most of these students may view science as a simple and objective endeavour. However, Tsai (1998) claims that the reverse may also take place. The epistemological views that students have about science may affect their actions and reasoning during experimental work. “If they perceive science as a collection of proven facts, they will focus on memorizing these “truths” and will attempt to prove them through codified procedures provided by the scientific method” (Tsai, 1998, p. 655). Similar concern was expressed by Fairbrother and Hackling (1997) who state that the actions and reasoning of students while “doing” science, is dependent on their views on the nature of

science (NOS). If they believe that science reveals the “truth”, then experimental work may be viewed as a process for the quest of genuine, faultless scientific knowledge.

Studies investigating the conceptions of the NOS of elementary and high school students, teachers and undergraduate science students have revealed that they often view science as an objective endeavour (Ryder *et al.*, 1999; Moss *et al.*, 2001; Abd-El-Khalick *et al.*, 2002). Science is regarded as the quest for the “truth” and the purpose of the “scientific method” is to prove a hypothesis to be correct. The process of experimental observation is a simple straightforward matter and does not involve human inference such as imagination, creativity and theoretical background. Experimental results are sacrosanct and there is much emphasis on the quantity of experimental data, which according to most students is equivalent to evidence (Ryder *et al.*, 1999). The acquisition and construction of scientific knowledge may depend on these two entities only. Repetition of an experiment results in the collection of more data such that they are reproducible, more accurate and hence reducing doubt concerning the reliability of the final result.

Therefore, on one hand, studies exploring science students’ views on measurement when “doing” science mainly during data collection, processing, comparison and interpretation, have shown that most students, at secondary and first year university level, display a dominant belief in the existence of a single, “true” value (Lubben *et al.*, 2001). On the other hand, studies on the NOS have revealed that the majority of students often hold a dominant objective view about the nature of science (Lederman, 1992; Ryder *et al.*, 1999; Abd-El-Khalick *et al.*, 2002). Therefore, the present work aims to investigate whether there is a relationship between first year physics students’ views on the nature of science and their views on the nature of scientific measurement.

2. Students' understanding of scientific measurement

The goal of a measurement is to increase the available knowledge about a measurand, which is the specific quantity subject to measurement. The measurement process involves the comparison of the measurand with a reference standard which is very often, but not always, manifested in some or other form of apparatus. The ISO (ISO, 1993) definition of a measurement result is "... the result of a measurement is only an approximation or estimate of the measurand, and thus the result is complete only when accompanied by a quantitative statement of its uncertainty" (Taylor and Kuyatt, 1994, p. 1). Uncertainty itself is defined as "a parameter associated with a measurement result that characterizes the dispersion of the values that could reasonably be attributed to the measurand."

Usually, the "measuring" process is dependent on the quality of the instrument in use, the skills and techniques employed and the context, either scientific or "everyday", in which it is performed. In the "everyday" domain, measurement is often characterized as "approximate" or a "rough estimate" (Lubben *et al.*, 2004). In the scientific domain, measurement, considered to be equivalent to evidence (Ryder *et al.*, 1999), is associated with experiment and is seen as the fundamental source for the generation of trustworthy scientific knowledge. Consequently, the whole "measuring" process in science can be regarded as an epistemic one whereby a thorough understanding of evidence is necessary. Millar (1996) characterises the understanding of evidence as the ability to evaluate the

effect of uncertainty in the data collected, recognise that it can be reduced but never completely eliminated, and decide whether any constructive conclusion can be derived from the data.

At any level, whether at secondary school or at university, much emphasis is often placed on “doing” science and students are actively engaged in practical work. However, many students do not have the required skills and concepts to deal with experimental work. Practical sessions are regarded as processes for replicating or illustrating the theoretical part of a course which has been introduced in lectures (Hart *et al.*, 2000). In many cases, according to Coelho and Séré (1998), a deep understanding of the nature of measurement is considered too complicated and time consuming for secondary and first year university students, and thus is not dealt with in detail.

Many studies have been carried out on students’ understanding of the declarative aspect of physics. Examples of such studies include: Hestenes (1987) on the understanding of mechanics, McDermott and Schaffer (1992) on introductory electricity, Ambrose *et al.* (1999) on single-slit diffraction and double slit interference, McDermott (1999) on light as an electromagnetic wave, and Vokos *et al.* (2000) on the wave nature of matter. Recently, more studies have been associated with the procedural aspect of physics, for example, exploring students’ views of measurements when doing experimental work (Séré *et al.*, 1993; Buffler *et al.*, 2001; Lubben *et al.*, 2001; Evangelinos *et al.*, 2002). These studies on measurement can be classified into two specific groups: surveys on science students’ understanding of the different aspects of measurement, and studies evaluating specific interventions aimed at improving science students’ understanding of measurement.

2.1 Studies on students’ understanding of measurement

Lubben and Millar (1996) investigated the views that secondary school students, aged between 11 to 16 years, have about repeated measurements, spread in data and methods for handling multiple measurements. A written questionnaire, dealing with the time taken for sugar to dissolve in water and for a toy car and tractor to travel a fixed distance, was

completed by 1000 students in the UK. From the outcomes of this study, an eight step model of progression was designed to model the development of students' reasoning. Allie *et al.* (1998) applied the Lubben and Millar (1996) model to classify and describe university science students' understanding of measurement.


The survey by Allie *et al.* (1998) also explored the actions and decisions of undergraduate students during experimental work, mainly when handling data. A written questionnaire was used, dealing with the purpose of repeating measurements, comparing two sets of data having similar means but different spreads and different means but similar spreads, and how to treat anomalous data. It was completed by 121 first year physics students from the University of Cape Town after an introductory course on measurement. The students generally had poor or no previous experience with experimental work. All the questions (probes) were based on the same experimental context. Figure 1 below provides an example of a probe in the measurement questionnaire.

The group of students decide to release the ball again from $h=400$ mm.
This time they measure $d=426$ mm.

First release: $h = 400\text{mm}$ $d = 436\text{mm}$
Second release: $h = 400$ mm $d = 426$ mm


The following conversations now take place between the students

We know enough. We don't need to repeat the measurement again.




A

We need to release the ball just one more time.



B

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



C

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

A	B	C
----------	----------	----------

Explain your choice.

Figure 1. Example of a probe in the questionnaire (Allie *et al.*, 1998).

Individual interviews, each lasting about thirty minutes, were carried out on a sample of twenty students to validate the items in the probes together with the responses provided. Analysis of the responses showed that the majority of the university students have a sophisticated justification for taking multiple measurements. They believe that many measurements are needed to calculate the average which reduces errors and is close to the “true” value. A small percentage of the students argued that repetition is needed for practice, to have a more accurate value or to choose the recurring value from the readings obtained. According to 56% of the sample, anomalous data must be excluded when processing the readings since they arose from “mistakes” while doing the experiment. From the 42% students who argued for keeping the anomalous data, 30% of them believed that all readings obtained in an experiment have to be considered when calculating the average while the remaining 12% stated that the complete range of the results also included that of the anomalous data. When comparing data, 48% of the respondents referred to the average values of the two data sets while 44% of them applied the notion of spread. However, according to the students, the term “spread” pertains mainly to the differences between the individual readings from each data set. Furthermore, only 3% referred to the overall spread in data and 8% to the “closeness” of the individual readings. The most sophisticated approach for comparing the data sets, the use of the average together with a value for the uncertainty, was employed by only 28% of the university students.

When compared to the survey on secondary school students by Lubben and Millar (1996), similar findings were obtained. Older UK students, the majority of the 13 and 16 year olds, have greater expertise in handling repeated experimental measurements. According to the older students, multiple measurements are needed to calculate the mean value. However, most of the younger participants, 11 year olds, believe that measurements must be repeated to be sure about the result obtained and to compensate for the differing experimental conditions. In some cases, multiple readings are considered to be routine in science. The presence of an anomalous datum was recognised by a minority of the students, irrespective of the age group, whereby older participants argued for its inclusion when calculating the average. For respondents who excluded the outlier, when presented with multiple measurements, the younger students choose the recurring value as their final result, while the 16 year olds preferred to calculate the mean of all the remaining readings. When

comparing data, most of the students, irrespective of the age group, referred to either the average value or the “closeness” of the individual readings in each data set.

Compared to the secondary school students from the UK, the students from Allie *et al.* (1998) were from completely different socio-economic backgrounds. However, the outcomes from these two independent studies, each with students having very different backgrounds and levels of science understanding, were consistent with each other. Similar views on measurement were reported for South African undergraduate chemistry students (Rollnick *et al.*, 2001). These findings confirm the robustness of student views on measurement across science subjects.

The study by Allie *et al.* (1998) also led to the creation of an additional level in the Lubben-Millar (1996) model. Some university students can recognize that variations in repeated data do occur and can use the concept of spread when comparing data, although they rarely associate the idea that a mean together with an uncertainty is needed when deciding whether or not two different data sets agree with each other. Hence, it was confirmed that the extended Lubben-Millar (1996) progression model can be utilized as a tool for identifying, classifying and describing the views of students on measurement when doing experimental work.

A separate study, implemented by Coelho and Séré (1998), provided further evidence to support these findings on students’ understanding of measurement. The sample consisted of twenty one (14 to 17 year olds) secondary school students in France engaged in taking measurements in elementary mechanics. Data for the study were collected from individual interviews or in groups of two or three students, each interview lasting for 45 minutes. The experiment was performed by the interviewer who put questions to the students while proceeding through the practical task. An illustration of the typical questions asked during the interviews follows below:

What do you think of this? Why have different results been obtained? Is there any result which is better than the other? If you had to express the measurement result, how would you do it? Why do you use average? Why keep four digits after the point?

(Coelho and Séré, 1998, p. 84)

According to the authors, these interviews helped to investigate not only what students say they “should do” (the concept) but also what they “actually do” (the procedure) while dealing with data. Furthermore, during the interview, they were encouraged to make predictions, comment on and explain their observations, and justify their arguments during the different phases of data handling. Hence, clarification can be obtained about ambiguous actions, concepts and words used during the activity. When the responses were analysed, it was found that most of these students believe in the existence of a “true” value which, according to them is a single, unique number. The “true” value can be obtained or approached by using more sophisticated instruments and improving the experimental conditions together with the processes used to gather the data. Many undergraduate physics students also mention that the “true” value exists. But they agree that, in practice, only a value close to the “true” value can be obtained because of imperfections in the instruments, the experimental methods, and the presence of external and “human” factors affecting the experiment (Evangelinos *et al.*, 2002). The sample in Coelho and Séré (1998) generally believed that it was impossible to get dispersion in data when the same quantity is being measured. If dispersion does occur it is because of “mistakes” while doing the experiment.

The studies described above deal mainly with students’ views of measurement when collecting, processing and comparing data. In a separate study, Masnick and Morris (2002) showed how students’ interpretation of data is influenced when they are presented with data sets which have different spreads, number of data points and varying differences between the individual readings and the average value. The survey was implemented on primary, secondary and undergraduate university students, aged between 9 to 20 years. The participants were requested to draw conclusions from the data collected and make predictions about the measurements when the experiment was repeated. The authors categorized the responses into four “levels of sureness”. The results showed that the students’ interpretation of data is influenced mainly by the sample size and the number of overlapping data points. College students prioritise the number and consistency of readings in a sample. They were found to be generally more confident about their conclusions and predictions with an increase in the number of measurements. In contrast, the younger participants displayed a lower “level of sureness” with an increase in the number of readings. Irrespective of the grade, the participants were less “sure” about their conclusions and predictions when the range of readings from the two data sets overlapped. The

students' interpretation of data was least affected by the quality of the instrument used, variability in the data sets and the presence of anomalous data.

2.1.1 The point and the set paradigm model

The data collected from a survey performed at university level by Lubben *et al.* (2001) on physics students' understanding of measurement led to the development of a paradigmatic model for measurement. This model can be used to identify, classify and explain the justification provided by students for an action. It differs from the Lubben-Millar (1996) model which emphasises mainly on describing the different levels of sophistication of students' views on measurement. The paradigmatic framework is characterised by the "point paradigm" and the "set paradigm". In this context, the term paradigm is used as a 'constellation of beliefs, values, techniques,.. shared by members of a given community' (Kuhn, 1970).

In the point paradigm, each measurement has the possibility of yielding either the correct value, often considered as the "true" value, or an incorrect value of a measurand. The focus is on treating each measurement on an individual basis independently of other readings. The data points are never combined in any way, except when a particular value has to be confirmed or rejected. The point paradigm is also characterised by the belief that only one single measurement is sufficient to establish the "true" value. If a series of measurements with dispersion are obtained, actions are based only on the individual data points, for example, the first or the recurring reading is selected to represent the final result and, data are compared on a one-to-one basis from the different sets of readings.

In contrast, the set paradigm is characterised by the belief that each measurement is only an approximation of the measurand. The best knowledge about a measurand is obtained by modelling all the data at hand to produce the best estimate (the reading itself when there is a single value or the average value calculated from an ensemble of measurements) together with an interval for the uncertainty of the measurand. Consequently, information gathered for a measurand can never be completely perfect.

Table 2 provides a summary of the criteria which characterize the “point” and “set” paradigms.

Table 2: Summary of the criteria which define the “point” and “set” paradigms (Buffler *et al.*, 2003, p. 2).

Point paradigm	Set paradigm
The measurement process allows you to determine the true value of the measurand.	The measurement process provides incomplete information about the measurand.
“Errors” associated with the measurement process may be reduced to zero.	All measurements are subject to uncertainties that cannot be reduced to zero.
A single reading has the potential of being the value.	All available data are used to construct distributions from which the best approximation of the measurand and an interval of uncertainty are derived.

The outcomes of the study by Lubben *et al.* (2001) were consistent with the findings of other studies performed on students’ understanding of measurement. A written questionnaire dealing with data collection, processing and comparison, and following a format similar to the written instrument used in the study by Allie *et al.* (1998) was completed by 257 first year university science students from the University of Cape Town at the start of the year. The participants had a similar background to the cohort described in Allie *et al.* (1998). Three probes, “Repeating Time” (RT), “Repeating Distance” (RD) and “Repeating Distance Again” (RDA) were concerned with data collection. According to students who use point reasoning, multiple measurements are useless. Measurements are repeated only for practice before taking a “perfect” reading or to choose the recurring value. In contrast, participants classified according to the set paradigm believe that measurements must be repeated in order to calculate a mean. Few students mentioned that the average value helps to minimise the differences that exist in data.

Two probes, “Using Repeated measurement” (UR) and “Straight Line Graph” (SLG), dealt with data processing. Students categorised according to the point paradigm, when processing data, choose either a specific value depending on its position in the data set or the recurring value from a series of readings to represent their final result. In contrast,

students associated with the set paradigm calculate the mean of a series of measurements. In some rare instances, a value for the uncertainty was also included. When plotting the best straight line, on one hand, students whose views on measurement were consistent with the point paradigm, use line segments to join all the data points or fit the line through most of the readings. On the other hand, students classified according to the set paradigm draw a straight line or a curve such that there are sufficient data points on either side of the straight line or the curve.

The last two probes were concerned with data sets comparison. The authors classified a response as “basic set comparison” when the emphasis was only on the mean value and “deep set comparison” when the students used the notion of average as well as the uncertainty value of the data points. The majority of the students’ responses were categorised as “basic set comparison” for the two data comparison probes whereby for the DMSS probe (Different Mean Same Spread) the “closeness” of the average value from each data set was compared. However, there were some responses which were classified as “deep set comparison” for the SMDS probe (Same Mean Different Spread) compared to the DMSS probe where the students failed to recognise that an average together with a value for the uncertainty is required for data sets comparison. The actions and decisions which are associated with the point and set paradigms are summarised in Table 3.

The study also revealed that there are inconsistencies in the use of both types of paradigms for the chosen action and the explanation given to support the action. Some students recognised that measurements must be repeated to calculate an average but they preferred to choose the recurring value or a value close to the mean as their final result. The students also outlined the appropriate procedure to plot a straight line graph but used line segments to join all the data points. Furthermore, it was found that the actions and reasoning of students are dependent on the experimental procedures of the study. For example, when collecting data, the students stated that multiple measurements are needed for the “Repeating Time” probe in order to calculate the mean. However, for the “Repeated Distance” probe they preferred to take repeated measurements from which the recurring value was then chosen. It is believed that the inherent variability nature of time may have motivated the students to use set reasoning.

Table 3: Actions and reasoning associated with the point and set paradigms (Buffler et al., 2001, p. 1153).

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 a single, “point-like” value rather than contributing to an interval. Only one 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 the 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 the 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 an 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 fit to all the data.	The best graphical representation of series of measurements is obtained by modelling the trend of the data.
Data set quality	For the same number of measurements, the better measurement is chosen to be the one associated with the smallest standard deviation.	The standard deviation is related to the precision of the measurement.
Data set comparison	The agreement of two measurements is related to the degree of the overlap of their intervals.	The mean and standard deviation define a confidence interval which is related to both the best estimate and the reliability of the measurement.

To summarise, the different studies described above were carried out on different backgrounds of students with different levels of science understanding, secondary level (Lubben and Millar, 1996; Coelho and Séré 1998), and university level (Allie *et al.*, 1998; Lubben *et al.*, 2001). Lubben and Millar (1996), Allie *et al.* (1998) and Lubben *et al.* (2001) collected data from written questionnaire together with interviews. Coelho and Séré (1998) preferred to use only interviews. The results obtained from these different studies were consistent with one another irrespective of the background and academic level of the sample, and the methods used to gather the data.

2.2 Evaluations of laboratory curricula

Coelho and Séré (1998) identified those concepts which can hinder or enhance the development of students' ability in dealing with data. The authors suggested that the belief in the existence of a "true" value can encourage students to improve their method of handling experimental data. They may take multiple measurements in order to obtain the "correct" value or be close to the "true" value. However, this conception can simultaneously convey the inappropriate meaning that differences in a set of data can be completely eliminated. By analysing the different sources of uncertainty and assigning values to each of them, students can be encouraged to consider the collected data as an ensemble, which can be combined and modelled through statistical procedures.

Buffler *et al.* (2001) designed a laboratory course which focuses on tools and procedures designed to shift students' reasoning from the point paradigm to the set paradigm. However, Lippmann (2003) is opposed to the total exclusion of the point paradigm view in favour of set reasoning. The author argues that, depending on the context in which measurements are taken, both the point and the set paradigms can be useful when dealing with data.

To evaluate their laboratory course, Buffler *et al.* (2001) researched 70 Science Foundation Programme students' understanding about measurement before and after a twelve week instruction from the laboratory course. The course emphasized the techniques of

manipulating statistical tools in order to model data. The point and set paradigms were used to categorise the participants' responses. Before instruction, most of the students were classified as having a strong point paradigm view. After instruction, there were still inconsistencies in the reasoning and actions of the students. Not all of them have shifted completely to the set paradigm. The main aim of this study is summarized in Figure 2.

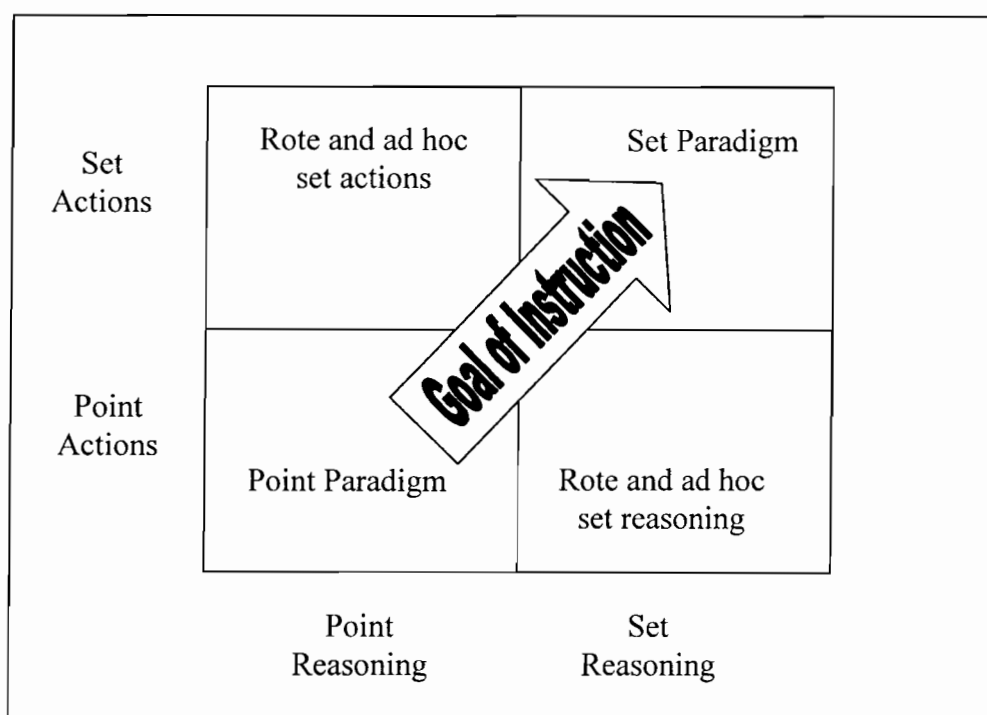


Figure 2. *The goal of instruction in relation to the point and set paradigms (Buffler et al., 2001, page 1154).*

According to the authors, the purpose of a laboratory course is to shift the students' "point actions and reasoning" to "set actions and reasoning". However, from the responses gathered in those probes which require a higher level of set reasoning, it was clear that students often use set reasoning by applying memorized statistical tools and procedures to deal with data in familiar conditions. They can be classified as "point actions" using "set reasoning". Furthermore, the authors concluded that it was difficult to switch the beliefs of those students whose actions are classified according to the set paradigm but decisions are associated with the point paradigm. The fourth category, "set actions and reasoning", meaning, those participants whose actions and decisions were both categorised according to the set paradigm, were rare in this study.

A similar study was performed on 53 participants from the mainstream first year physics course by Volkwyn *et al.* (2004). The students generally had a good academic and science background and had intensive hands-on experience with practical work at school. The mainstream students' views on measurement were probed before and after an intensive 24 weeks instruction from the laboratory course. On analysis of the responses for the data collection and processing probes, a minority of the students were associated with the point paradigm before and after instruction. However, for the data comparison probes, before instruction, 34% of the students were categorised as “consistent point reasoning” while 66% of them used both types of paradigms. Even after instruction, only 19% of the students used set paradigm reasoning consistently for the three data comparison probes.

Similar results were presented by Séré *et al.* (1993) who studied the conceptions of twenty French first year university physics students, aged between 18 to 20 years, when handling experimental data. The intervention consisted of theoretical exercises on measurement and two laboratory sessions dealing with optics and electricity. A test assessed the students' gain in the application and interpretation of statistics in measurement. The participants were provided with a booklet consisting of ten open ended questions, each question on a separate sheet, which they were required to complete while proceeding through their experimental task (measuring the focal length using two different methods).

For example:

Page 1: Carry out *one measurement* of the focal length f of the lens by autocollimation. Give this value an interval.

Page 2: Carry out a second measurement of f . Give it with an interval. If these two measurements are not completely identical, explain and comment on this fact.

Page 3: Do you think you are able to judge if one measurement is ‘good’ (usable) and the other is less good? After these two measurements, are you now able to give a result? If yes, which result?

(Séré *et al.*, 1993, p. 430)

During the task, the students worked in pairs. The use of the open-ended booklet helped in comparing the actions and reasoning of the students in different experimental situations

(optics and electricity) and simultaneously indicated if there was an improvement in their understanding of measurement. Four students were also interviewed individually to identify their conceptions and difficulties when dealing with data and to elucidate the measurement concepts they have acquired after instruction. Results obtained from this study revealed that even after instruction, these students did not recognize the usefulness of multiple measurements. Variation in data was claimed to be due to “carelessness” or environmental influences which occur while doing the experiment. No distinction was made between “systematic” and “random” errors. The students had vague notions about the terms “precision” and “accuracy” and they firmly believed that a single measurement is sufficient to yield a final “true”, unique value.

The three independent studies revealed that the specific intervention used was effective in developing the students’ ability to deal with the tools and procedures for data analysis. However, irrespective of the students’ academic background and language proficiency, no significant change was detected in their understanding of the nature of scientific measurement. It was furthermore difficult for them to adopt a consistent and extensive notion of set reasoning. Hence, it was concluded that students’ skills in using statistical calculations for data analysis are not related to their understanding of the underlying concepts of the statistical procedures.

Most of the present (traditional) laboratory courses are based on the “frequentist” approach while recently designed (new) laboratory courses are based on the “probabilistic” approach. In the “frequentist” approach, data are analysed in terms of frequencies. It is appropriate when dealing with large sample size (20 to 30 readings) where the data points are modelled and represented in terms of numbers and intervals. However, this approach is limited as statistical analysis cannot be performed on a single value or on a small sample size. In the “probabilistic” approach, the probability theory is used to infer conclusions about a measurand directly and logically. It can be applied to perform data analysis either on large or small sample sizes as well as on one single value (Allie *et al.*, 2003).

Evangelinos *et al.* (2002) compared first year physics students’ views on measurement before and after instruction from the traditional (frequentist) and new (probabilistic) laboratory course. The context involved a single measurement reading. The sample in the

study was from the Aristotle University of Thessaloniki, whereby 16 students were instructed from the new laboratory course and 41 from the traditional laboratory course. The students were familiar with the theoretical aspect of physics but had little or no previous experience with practical work. Before instruction most of the participants believed that a single measurement is only an “approximate” value because there are many sources of imperfections which make it difficult to obtain the “true” value. A minority of the participants suggested that an “exact” value exists as physics is an “exact” discipline. Around 50% of the sample adhered to the notion of “interval” which according to them provides a greater possibility for the “correct” value to fall within the range of the collected data. After instruction from the new laboratory course, 93.7% of the students discarded the notion of “exact”, “approximate” single measurement and focussed mainly on the concept of “interval”. The study showed that the new laboratory course was effective as students were able to apply the concept of uncertainty and probability to perform data analysis either on a single measurement or on a different sample size. It succeeded also in developing the students’ understanding about the difference between an exact and an uncertain value.

Similar outcomes were obtained from the study by Buffler *et al.* (2003) who evaluated the new laboratory course, the ‘Introduction to Measurement in the Physics Laboratory, a probabilistic approach’ (Buffler *et al.*, 2001). The study was performed on 106 students. Before instruction, 73% of the students were classified as “consistent point paradigm”. After instruction, 89% of the sample shifted to being classified as “consistent set paradigm”. The new laboratory course appeared to be more effective in its aim compared to the traditional one, based on the “frequentist” approach, where even after instruction students seemed to use both types of paradigms for the different measurement probes and there were contradictions between their actions and decisions when dealing with data.

A separate study was implemented by Deardorff (2001) on students’ views on measurement and uncertainty. The sample was made up of undergraduate science students from the North Carolina State University and the University of Hokkaido in Japan. Data were collected from written questionnaires which were adapted from the Laboratory Procedures Questionnaire conceptualised by Allie *et al.* (1998) together with new instruments designed for the study. Interviews were also conducted. The study shows that

traditional laboratory course fails to develop students' understanding of measurement and uncertainty. Even if the students become more skilful in calculating the mean and standard deviation, they do not understand and recognise the role of uncertainty in data analysis and it is difficult for them to relate the concept of uncertainty to the concept of evidence.

Lippmann (2003) designed the scientific community laboratory (SCL), aimed at helping students to understand the concept of measurement and uncertainty, and also teaching them the importance and role of uncertainty in an experimental task. Data were collected using the SCL and, as a control, using the traditional laboratory tasks. A multiple choice survey, administered electronically was completed by 120 students before and after instruction from the SCL. According to Lippmann (2003), the electronic multiple choice method is less time consuming. It is easy to administer and analyse. It minimizes the risk of the participants selecting the option which appears most scientific instead of the one which they most closely agree with. However, in the electronic multiple choice survey participants are forced to think within the framework of the researcher, select an explanation instead of reflecting on the probe and creating their own response.

The survey probed students' ideas when processing data, comparing and combining two sets of data. Analysis of the responses showed that before and after instruction from the SCL, a high percentage of students processed their data by calculating the mean from the series of measurements. For the four probes concerned with data sets comparison, after instruction, a significant increase was noted in the percentage of students who used the notion of overlapping spread to decide whether two sets of data agree, 48% and 47% respectively for the two cases where only the average value of five readings were presented and, 53% and 60% respectively for the two data comparison probes whereby the average and the uncertainty value for the two sets of data were calculated (Lippmann Kung, in press). Moreover, from the study by Lippmann (2003), there was a shift from 21% to 42% of students with the notion that the average together with a value for the uncertainty of each data set is required when combining data. The results indicated that the SCL was successful in developing the students' concepts about the use of intervals for data sets comparison. It was also effective in teaching students to use the point and set reasoning in the appropriate context and, overall, after instruction, there was an increase in the number of students who used set paradigm reasoning.

2.3 Summary

All the different studies described above have come to the same conclusions. Science students, whether secondary school or first year university, strongly believe in the existence of an ideal, unique value, they do not necessarily recognize the usefulness of multiple measurements and do not understand the concept of uncertainty when analysing data. Even after intensive instruction, the traditional laboratory courses failed to change the students' views from this standpoint. New laboratory courses which are based on the "probabilistic" approach were thus designed and appeared to be more effective in developing the university physics students' understanding of measurement.

The paradigmatic model for measurement was developed and used for many of the studies at the University of Cape Town. It was found to be a useful tool for classifying and explaining the actions and the justifications of students during the different stages of measurement, mainly, data collection, processing and comparison. Furthermore, the paradigmatic framework can be used to evaluate the effectiveness of new laboratory courses designed to shift students' views on measurement from dominant point to consistent set paradigm reasoning.

Recent studies showed that students used different epistemological views of the nature of science when dealing with data in different scientific context (Séré *et al.*, 2001). The type of paradigm used may be dependent on the domain, either scientific or "everyday" domain, in which the measurement process is performed (Lubben *et al.*, 2004). Hence, the motives for students to use either type of paradigm, especially the point paradigm view which is displayed by a vast majority of first year physics students, require further investigation.

3. Students' understanding of the nature of science

People's (students, teachers and the general public) understanding of the nature of science (NOS) can be defined as "the epistemology of science, science as a way of knowing, or the values and assumptions inherent to the development of scientific knowledge" (Lederman, 1992, p. 331).

The understanding of the NOS is of prime concern to scientists, philosophers, historians and sociologists of science as well as science educators. Ryder *et al.* (1997) provided two main reasons for an adequate understanding of the NOS. Firstly, the development of students' scientific concepts is dependent on their views on the nature of scientific knowledge. Secondly, an understanding of the NOS will allow students to make more informed and appropriate decisions as far as science is concerned in their daily life. Surveys carried out on public understanding of science, engineering and technology (PUSET) showed that most people respond to scientific issues by giving vague, unpersuasive answers, thus showing a superficial understanding of the NOS. In South Africa, a study by Laugksch and Spargo (1999) on 4223 university entrant students showed that the majority of these students have a low level of scientific literacy. Moreover, recently, the development of students' understanding of the NOS was included as one of the objectives of the new secondary school science curriculum in South Africa.

Much controversy exists on what constitutes an adequate understanding of the NOS. According to Lederman (1992), the adequate understanding of the NOS is characterized by the notion that scientific knowledge involves a combination of observations and human inference such as creativity, imagination and conceptual background. It is socially and culturally embedded. Furthermore, it is subject to change and can be modified with the accumulation of new information. The required understanding of the NOS is also described by the ability to distinguish between inference and observation as well as between a theory and a law.

Usually, students acquire scientific knowledge from a variety of sources, namely, science magazines and documentaries, from school or through discussions on scientific issues with the result that views displayed on the NOS may be inconsistent and are dependent on the scientific context under discussion (Ryder and Leach, 2000). Consequently, researching people's views of the NOS can be complex as it deals with the epistemology of science. Most of the studies carried out on the understanding of the NOS have been aimed at high school and elementary school teachers and students. Studies on undergraduate science students have been undertaken to a much lesser extent.

Lederman (1992) has grouped the research done on understanding of the nature of science under four headings:

- a) Assessment of student conceptions of the nature of science;
- b) development, use, and assessment of curricula designed to “improve” student conceptions of the nature of science;
- c) assessment of, and attempts to improve, teachers’ conceptions of the nature of science; and
- d) identifications of the relationship among teachers’ conceptions, classroom practice, and students’ conceptions.

(Lederman, 1992, p. 332)

3.1 Studies on students' conceptions of the nature of science

3.1.1 Students' understanding of the relationship between evidence and theory

Leach *et al.* (1997) investigated the views that secondary school students in the UK, aged between 9 to 16 years, have on the NOS. The participants were provided with different questions dealing with society, philosophy, nature and economy. They were required to classify these questions as scientific, non-scientific or unsure, followed by reasons to support their choices. The students were also interviewed in pairs. The participants expressed three main views for categorising a question as scientific or non-scientific. The majority of the students in the age group from 9 to 12 year olds believed that the domain of the issue under consideration in a question is the key for classifying the question as scientific or non-scientific. Most of the 9 year olds were of the opinion that a scientist's interest in a question is the criterion for categorising the question as scientific or non-scientific. Students between 12 and 16 year old mentioned the applicability of experiments for delineating between a scientific and a non-scientific question. Explanations, with different levels of sophistication, were provided for the use of experiments in a scientific endeavour. Students in the age group from 9 to 12 year olds believed that experiments are needed as they lead to improvements in everyday life and new discoveries in science. The older students, between 12 and 16 year old, expressed more sophisticated views. According to them, scientific experiments provide reliable evidence which is used to "evaluate" a theory.

From these findings, the authors grouped and described the main NOS views of the students. Phenomenon-based reasoning, mostly displayed by the 9 year olds, does not distinguish between theory and evidence. Experiments are viewed as processes for replicating the required behaviour of a phenomenon and to prove that a theory is correct. In relation-based reasoning, theory and evidence are regarded as two separate entities but

their relationship is considered to be a simple matching process. Evidence originates automatically from experiments and experimented evidence is regarded as the only available source of information for building a theory. Most of the students in the sample, for any age group, used relation-based reasoning. Finally, in model-based reasoning, displayed by a minority of the 16 year olds only, the difference between theory and evidence is recognized. In addition, students with this category of reasoning claim that the reliability and validity of a theory need to be checked through the evidence obtained in the actual experiment.

At tertiary level, Ryder *et al.* (1999) described the views that final year undergraduate science students from Leeds University have on three aspects of the NOS, namely, the relationship between scientific claims and data, the social aspect of science, and scientists' preference for a topic to be researched. The sample in the study was made up of 11 students of mixed gender and academic ability from the chemistry, biochemistry, earth science and genetics department. The context was the work on a final year project varying from laboratory investigation, computer modelling, data base analysis to field work. The project spanned over a period of 5 to 8 months and data for the study were obtained by conducting interviews before, during and after the completion of the project. According to the authors, these interviews helped to construct the various NOS profiles displayed by the students for the different scientific contexts. However, the use of interviews only, mainly for studies on understanding the NOS, is contested. There is language problem, the difficulty in articulating the NOS views using the appropriate words, with the result that the responses provided by the participants may have a disparate meaning to the researcher's interpretation (Leach *et al.*, 1997).

According to the majority of the students, the reliability and validity of scientific claims are dependent on experimental results only. A theory is either accepted or rejected on the basis of experimental evidence. It is suggested that students with this category of reasoning tend to view scientific claims (theories) and data (evidence) as two separate entities. A minority of the students emphasised the role of society and peer review for the acceptance of a scientific knowledge claim. The few students who did not distinguish between a theory and evidence stated that the aim of an experiment is to yield reliable data which are used to describe a theory. In some rare instances, students mentioned that in principle there

is no absolute proof. A scientific theory can also be evaluated by comparing its coherence with other theories. Two main views were expressed by the students when probed about scientists' choice of topic for implementing a research. Either scientists choose those areas where they will benefit financially or where more improvements and discoveries can be made to better the quality of life. Lastly, most of the students recognised that scientific endeavour is not an individual pursuit.

Studies on understanding of the NOS also include how students relate experimental evidence to a scientific theory (Leach, 1999). Data for the study were obtained from a sample of 190 secondary school students aged between 9 to 16 year olds in the UK. The context of the survey was based on the topic of electric circuits. Four observations (evidence) and four relevant explanations (theories) were provided. The participants had to choose a theory which best explains the observations, generate predictions about the behaviour of the electrical circuit and elaborate on their predictions. The trend in reasoning, for the different age groups, was identified for the three stages of the task. Most of the older students, the 16 year olds, treat the given observations as evidence and select a theory based on the given observations. In contrast, the majority of the younger participants, the 9 year olds, referred to their prior knowledge for selecting an explanation. A significant decrease was noted, from 9 to 16 year olds, in the number of students who used prior knowledge to generate and evaluate their predictions. It was also observed that the 9 year olds made "ad hoc modifications" to the selected theory when contradictions arose between the selected theory and the evidence. Kuhn *et al.* (1988) reported similar findings whereby younger students modified either a theory or evidence in order to fit their prior beliefs. The study by Leach (1999) showed that three main approaches were used when dealing with theory, evidence and prediction. Firstly, students treat either their existing knowledge about a subject matter or the given observations as evidence. Secondly, the predictions made are based on prior knowledge. Finally, the actions and reasoning of students for selecting a theory and relating it to evidence are influenced by their prior understanding of a subject matter.

For the case of adults (Schauble and Glaser, 1990), the explanations provided to justify their reasoning about a subject matter are based only on evidence gathered from the particular study. However, the authors concluded that similar to children, adults also use

their existing knowledge when interpreting experimental evidence. They furthermore tend to reject evidence which contradict their prior beliefs. It was revealed that students from 9 to 20 year olds refer to evidence (data) obtained in a given experiment to draw conclusions and make predictions only in cases where they have no theoretical background about what is being investigated (Masnick and Morris, 2002).

In a separate study, Paula and Borges (2003) investigated how young students, aged 13, choose and relate available evidence to support their view about a “scientific claim”. Data were obtained by interviewing the students in groups of two. The task consisted of questions dealing with the shape of the Earth. The authors classified the two sources of evidence provided as “direct” (satellite pictures for the shape of the Earth) and “indirect” (written explanations about the shape of the Earth). Two main strategies were employed for relating evidence to a scientific claim. Firstly, the students utilised only the “direct” evidence as decision for their actions. They referred mainly to the pictures which according to them are more concrete. They can see the shape of the earth from the pictures and hence are more certain about their conclusions. Secondly, they used both the “indirect” and the “direct” evidence which are combined, compared and contrasted thus leading to more advanced and complex explanations to support their scientific claims. According to the authors, the use of models can help students to recognise the distinction between a theory and evidence and also understand the relationship between these two entities. Moreover, the use of models can lead to the development of students’ views about the nature of scientific theories which is of crucial importance for an adequate understanding of the NOS.

Ryder and Leach (2000) explored science students’ views on the role of experimental data and theoretical models in the interpretation of the data. The survey was implemented with 731 students (upper secondary and university) from five European countries. Data were collected from interviews and a written questionnaire. The study presented two groups of scientists’ interpretation of data, each using a different theoretical model which described the properties of a superconductor when transferring electricity. According to the authors, the chosen context guaranteed that the students would not refer to any prior knowledge which might influence their decisions in this study. When asked which group’s interpretation of data they most agree with, 33% of the students referred to a view

associated with “model” while 27% of them focused on the need for more data. Only 18% of the participants mentioned that it is impossible to decide which group’s interpretation of data is better as in principle there is no absolute truth in science. When probed about the steps to be followed in order to draw a conclusion, 47% of the students were classified as using data-focused views where the focus is on the quantity (rather than the quality) of data and only 14% of them emphasised the role of theoretical models for data interpretation. Students with data-focused views are of the opinion that the collection of more data is equivalent to more accurate results which therefore reduce doubt about a conclusion. The authors concluded that students do not appreciate the role of theoretical models in data analysis. Much emphasis is laid on the quantity of data and students fail to recognise that the theoretical information encompassed by a model is also required for data interpretation. Moreover, students cannot articulate a clear explanation for their definition of a model.

The different studies described above probed secondary and tertiary students’ views on the NOS, mainly their conceptions on the relationship between a theory and evidence. It was found that the majority of younger students, 9 to 16 year olds, make no distinction between a theory and evidence (Leach *et al.*, 1997) thus contrasting with university students who appear to view scientific claims and data as separate entities (Ryder *et al.*, 1999). There is no significant difference in the strategies employed by students (Leach, 1999) and adults (Schauble and Glaser, 1990) for relating a theory to evidence. However, students do not demonstrate an understanding for the role of theoretical models in data analysis. Their interpretation of data is based solely on the quantity of data collected (Ryder and Leach, 2000). Moreover, irrespective of being from secondary or tertiary level, experiments are regarded as the key for distinguishing between a scientific and a non-scientific knowledge.

3.1.2 Students’ understanding of the NOS and experimental work

According to Tsai (1998), students’ images of science may affect their actions and decisions during laboratory activities. Hence, a study was implemented to investigate the relationship between students’ views on the NOS and their learning during experimental work. The sample was made up of 25 Taiwanese students aged between 13 to 14 years.

The students' views on the NOS were probed using Pomeroy's questionnaire and their perceptions about the actual and the preferred laboratory environment were explored using the Science Laboratory Environment Inventory (SLEI). The students' interactions during laboratory sessions were also recorded. Interviews were conducted with 20 participants in order to validate the responses.

The Pomeroy's questionnaire consists of agree/disagree scale statements where participants' views on each statement are labelled from "strongly agree" to "strongly disagree" and are accompanied by numerical values, 5 to 1. Likert type scale written instruments have numerous imperfections. The drawbacks are mainly concerned with the validity of the data and the data interpretation methods. These questionnaires are based on assumptions and are open to many misinterpretations (Lederman and O'Malley, 1990). Misunderstanding may arise from the words used to structure the items. It is believed that participants will interpret the words and understand the statements in the same way as the developers, and a response will be selected with reasons which are compatible to that of the researchers (Aikenhead *et al.*, 1989). Often, the researchers' prejudice and personal views on the NOS are reflected in Likert-scale statements (Lederman *et al.*, 1998).

Tsai (1998) categorised the participants' NOS views as either "constructivists" or "empiricists". According to the author, a "constructivists" view is characterised by the notion that scientific knowledge is tentative, involves human invention and is dependent on peer consensus. An "empiricists" view is defined by the belief that scientific knowledge is infallible, static and is dependent on experimental results only. The data show that "constructivists" generally prefer an open-ended, cooperative learning and theory integrated laboratory environment. They emphasise the importance of peer consensus before reaching a conclusion about an experimental outcome. During a laboratory activity most of their time is spent conducting the experiment, discussing, analysing data and sometimes relating the experimental data to the theoretical aspect of the investigation. In contrast, the "empiricists" are mostly concerned with manipulating the instruments "very carefully" and proceeding through the experiment by following the prescribed steps in order to obtain the expected result. When asked about the purpose of a laboratory activity, the "constructivists" state that it "illustrates the constructive process of scientific knowledge" while the "empiricists" focus on "verifying the truths and validate the

correctness of scientific laws or rediscover proven facts” (Tsai, 1998, p. 668). Furthermore, the “empiricists” believe that laboratory activities help in the memorisation of scientific concepts as opposed to the “constructivists” who emphasise the understanding of the theoretical aspect of a subject matter.

In a separate study, Séré *et al.* (2001) investigated the NOS views utilized by science students (university and upper secondary level) when dealing with measurement in different scientific disciplines. A written questionnaire was administered to 368 participants. Three questions were concerned with the NOS dealing with the interplay between data and a theory, the possibility of having different interpretations for the same data collected and the students’ actions and reasoning when experimental and theoretical results do not agree. For the measurement question, the respondents were provided with three situations, each with two sets of readings together with their respective mean value. In each case, the data sets had different characteristics in terms of spread, variability between the individual data points and the presence of recurring values. The NOS views drawn upon by the students for their measurement decisions were classified according to an ontological and epistemological framework.

Analysis of the NOS responses showed that students considered that a theory rather than data is required first when constructing scientific knowledge. It is the theory which guides the collection and the analysis of data. According to the majority of the participants, the interpretation of data is influenced by a scientist’s conceptual background. A high percentage of students, 54%, attributed discrepancies between experimental and theoretical results to “human errors” and stated that the experiment needs to be repeated. Decisions referring to either “hypotheses” or the belief that deviations between data and theory will always exist were used by 39% and 24% of the sample respectively. For the measurement question, when presented with two data sets having the same mean, most of the students chose to calculate the difference between the highest and lowest value from each data set before making a decision. However, when provided with two sets of data with differing mean, their actions were based on selecting either an individual measurement or a recurring value. Only 10% of the sample used the notion of uncertainty for comparing the two data sets. Some of the students, 12% of them, believed in the existence of “a true or an

official value”. According to them, the measurements obtained in an experiment must be compared with the “accepted value” before concluding about a theory. When dealing with two data sets having different mean and different spread, most of the students referred to the recurring value for making a decision. The authors concluded that students use different epistemological and ontological views on the NOS when handling data in different scientific contexts. Their views on what constitute reliable experimental data, how data are processed, interpreted, evaluated and related to a theory for the construction of a conclusion are highly dependent on the context under consideration and the epistemological views about science they draw upon from the different scientific domains. In fact it was observed that “students’ reasoning tends to be context bound, with little commitment to generalized characterization of ‘the nature of science’ ” (Leach *et al.*, 1997, p. 160). Moreover, Séré *et al.* (2001) reported that the complexity of the questions in a study also influences the students’ responses for the different probes.

In a study done at tertiary level, Ryder and Leach (1999) showed how students’ epistemological views about science affect their actions and decisions during project work. The sample and the projects used in the study were similar to those described in Ryder *et al.* (1999). On one hand, some of the projects required a thorough understanding of the skills involved in manipulating the technical aspects related to the field of study. On the other hand, the remaining ones focussed mainly on the nature of scientific knowledge and the relationship between a theory and evidence where the participants had to demonstrate a thorough understanding about the epistemology of science. Four of the students engaged in the projects involving the epistemology of science, according to the authors, had the required understanding of the NOS. In only one case, the student’s views about data and knowledge claims hindered the progress of the participant’s project work. The main aim of the student’s project was to collect experimental data and relate them to the different models provided in the project in order to validate and distinguish among the models. However, the student focused only on repeating the experiment to get better, more accurate and reliable data. No attempt was made to interpret the data collected in terms of the different theoretical models involved in the project. Consistent findings were obtained by Ryder and Leach (2000) whereby the majority of the students focused mainly on the quantity of readings thus ignoring the role of theoretical models when interpreting data.

To summarize, the three independent studies described above cover a different line of research on understanding of the NOS. Instead of eliciting the students images of science (secondary and university), they aimed mainly at exploring how students' NOS views influence their actions and decisions during either a laboratory activity or a project work. It was found that students' views on the NOS are related to their views on the purpose of a laboratory activity and their perceptions of the actual and their preferred laboratory environment (Tsai, 1998). At university level, Ryder and Leach (1999) showed that the students' NOS views play a crucial role in how they deal with an investigative project task. The students normally draw upon different epistemological views about science when dealing with data, depending on the scientific contexts under consideration (Séré *et al.*, 2001).

3.1.3 The development of students' understanding of the NOS

Moss *et al.* (2001) investigated whether there was a development in high school students' understanding of the NOS after working on four different projects namely, "watershed", "forest ecosystem", "salmon restoration" and "population dynamic modeling". The study lasted over one complete academic year. The sample consisted of five students of mixed gender and academic ability from the Conservation Biology class. A model, subdivided into views on the nature of scientific enterprise and views on the nature of scientific knowledge, was designed for the study. The former explored students' conceptions on the aims of science, its social aspect, the characteristics of a scientific endeavor and the role of creativity, imagination and the scientific method in science. The section on the nature of scientific knowledge was grouped under three headings, namely, the difference between a scientific and non-scientific knowledge, the limitations of scientific knowledge, and the tentative and developmental nature of scientific knowledge. Data for the study were collected from interviews, the syllabus, tests, quizzes and project guidelines. When probed about the nature of scientific enterprise, the students initially believed that there is a distinction between a scientific and a non-scientific investigation but they cannot articulate a clear understanding for the difference. The majority of the students claimed that science involves the comparison of a theory with data but they do not recognize the predictive

power of science. After the completion of the projects, it was found that the students no longer viewed the relationship between a theory and evidence as a simple matching process. They mention that science involves the interplay among variables instead of referring to science as “explaining”, “describing” or “uncovering” information. Most of the students recognized the importance of logic, creativity and imagination in science and acknowledged the influence of society on the progress of science. Finally, the students’ beliefs about the existence of a scientific method for “doing” science remained unchanged. According to them, the scientific method is equivalent to the steps used to write a laboratory report. In contrast, a more complete development was noted in the students’ views of the nature of scientific knowledge. They focused on experiments and evidence to distinguish between a scientific and a non-scientific knowledge. They recognized that scientific knowledge may be limited and may not provide complete answers. There was a shift from the belief that scientific knowledge is static to scientific knowledge is subject to change with the accumulation of new information. They furthermore mentioned that the framework of existing scientific knowledge can be broadened through experimentation.

The authors concluded that the students’ conceptions of the different aspects of the NOS did not develop fully over the year. In cases where an evolution was noted in the students’ NOS views, it was possible to relate the development to the type of project work they were engaged in. For example, those students involved in the “population dynamic modeling” project developed more sophisticated views about the relationship between a theory and data. They understand the complex mechanism involved between these two entities and recognize that a theory does not emerge automatically from the data collected. The “forest ecosystem” project, where no satisfactory conclusion about the investigation was reached, is believed to have developed the students’ understanding that scientific knowledge may have limited explanatory power. Finally, the “salmon restoration” project is believed to have enhanced the students’ concept about the social aspect of science. Moss *et al.* (2001) also pointed out that the use of a model provides a set of criteria which may be used to interpret and describe students’ views on the aspects of the NOS probed in a study. This method of analysis also facilitates the identification of those NOS conceptions which may have developed after a specific intervention.

At university level, Ryder and Leach (1999) identified the changes in the images of science according to the category of activities involved in a project work. Students engaged in experimental work dealing with data collection, recognise that reliable data do not emerge automatically by following experimental procedures. Data handling activities are complex processes and conflicts among scientific claims are not resolved by using experimental data only. The students acknowledge that data at hand can be interpreted in different ways. Therefore, they realise that science involves human inference and creativity and imagination play a crucial role for its progress. The authors concluded that final year projects have to deal more with the epistemology of science. More activities which will develop and promote the students' epistemological scientific concepts have to be added. These include viewing videos related to the project work, interacting and engaging in discussion with other post graduate students, professional researchers or the supervisor and reading numerous research papers and science journals.

3.2 Studies on teachers' conceptions of the nature of science

It was assumed that teachers' conceptions of the NOS may influence their students' NOS beliefs (Lederman, 1992) and there are many factors which hinder the NOS transfer from teachers to students (Lederman, 1999). The main findings from surveys investigating teachers' conceptions of the NOS typically revealed that teachers do not have an adequate understanding of the NOS. Teachers generally believe that science is based only on scientific experiments from which infallible scientific knowledge is obtained. They are of the opinion that a theory is static but will change only if new experimental evidence is obtained. Moreover, on proving a theory repeatedly, it becomes a law. Teachers do not usually recognise the use of creativity and imagination in science and they mention that society, culture and politics have no importance for the progress of science (for example, Lederman, 1992; Abd-El-Khalick and Lederman, 2000; Dekkers and Mnisi, 2003).

Mnisi and Dekkers (2003) investigated the NOS views of 14 science teachers from South Africa. The teachers were either teaching at primary or secondary level and had 14 to 15 years of experience. They were involved in an Advanced Certificate in Education (ACE) programme. The authors classified the participants who recently joined the ACE programme as “beginners” and those who completed the ACE programme as “near-completers”. The “beginners” had no prior instruction about the NOS while the “near-completers” were involved in discussions on the history and philosophy of science. They had to design and teach science lessons which include the NOS. Data for the study were collected from the Views Of Nature of Science (VNOS) questionnaire which was completed by both groups of participants.

The VNOS is an open-ended written instrument developed by Lederman and O’Malley (1990). It normally consists of seven to ten questions based on the criteria which characterise an adequate understanding of the NOS. It can be modified into different versions, VNOS-A, VNOS-B and VNOS-C, depending on the sample involved in the study and the aspect of the NOS to be probed. The VNOS questionnaire aims mainly at analysing and building up a profile for the teachers’ and students’ concepts on the different aspects of the NOS as opposed to multiple choice questionnaires which end up labelling participants as having “adequate” or “inadequate” NOS understanding (Abd-El-Khalick *et al.*, 2002). Figure 3 provides an example of part of the VNOS questionnaire.

1. After scientists have developed a theory (e.g. atomic theory), does the theory ever change? If you believe that theories change, explain why we bother to learn about theories. Defend your answer with examples.
2. What does an atom look like? How do scientists know what an atom looks like what you have described or drawn?
3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.
4. How are science and art similar? How are they different?

Figure 3. *Illustration of some of the questions in the VNOS instrument (Abd-El-Khalick et al., 2002).*

When completing the VNOS, the participants are generally required to provide written justifications for their ideas expressed. They are given the opportunity to argue their own views about the issues being discussed. Usually, the completion of the VNOS questionnaire is followed by in depth individual interviews in order to validate both, the respondents' interpretation of the VNOS questionnaire and the researchers' interpretation of the written responses obtained. During the interviews, participants are required to explain what they understood from the items, justify their written statements thus ensuring that their written responses are consistent with those expressed during the interview. They are also requested to clarify vague or contradictory arguments and words used when completing the instrument (Abd-El-Khalick *et al.*, 2002).

Mnisi and Dekkers (2003) found that both groups of participants believe that science is based mainly on observations and experimental evidence. Experiments are needed to “prove” instead of “supporting” a theory. Neither the “beginners” nor the “near-completers” distinguished between inference and observation. When probed about the nature of scientific theories, 29% of the “beginners” stated that a theory is static while all the “near completers” recognised that a theory is subject to change when new information is obtained. Both groups of participants did not have a clear concept of a theory and a law. According to the teachers, a theory becomes a law after the theory has been proven repeatedly. The majority of the “beginners” failed to recognise the importance of creativity and imagination in science compared to the “near completers” who expressed various views for its application during a scientific investigation. Both groups of participants did not appreciate the role of the conceptual background and personal beliefs of a scientist in the development of scientific knowledge. Lastly, all the “near completers” mentioned that society and culture are needed for the progress of science while only 14% of the “beginners” expressed a similar view.

In a separate study, Abd-El-Khalick *et al.* (1998) assessed pre-service secondary science teachers' conceptions of the NOS after instruction from a course involving the epistemology of science. The sample consisted of 14 teachers who were in their fifth year of Masters of Arts in teaching degree. Most of them had Bachelor of Science or Masters in science degrees before enrolling for the MAT course. Data for the study were collected from the VNOS questionnaire and interviews.

All the participants in the study stated that scientific knowledge is based on observations and experimental results. They acknowledged the tentative nature of a theory. They mentioned that creativity is used when planning, designing an experiment or for the formulation of a conclusion. The involvement of a scientist's conceptual background for the construction of scientific knowledge was also recognised. Distinction was made between an inference and an observation. However, the teachers do not have a clear understanding about a theory and a law. According to them, a law is obtained after proving a theory and hence has supremacy over the theory. Finally, progress in science is seen as completely detached from the influence of culture and society. A follow up study by Abd-El-Khalick (2005) shows that after instruction from a philosophy of science course, pre-service science teachers are more inclined and apt to include aspects of the NOS when planning their teaching lessons and they design various strategies to teach and transfer the NOS. Moreover, they reflect on the reforms required in their teaching strategies and consider the appropriate vocabulary to be used in order to impart an NOS concept which is consistent with their own.

The two separate studies, (Mnisi and Dekkers, 2003 and Abd-El-Khalick *et al.*, 1998), were carried out using a common research approach and on two different backgrounds of science teachers. The findings gathered were consistent in many aspects. They indicate that teachers do not have the required NOS conceptions to teach the NOS. Even after instruction it was still difficult to identify development in their understanding on all the seven criteria which comprises the NOS.

Lederman (1999) carried out a study on five biology teachers to investigate whether there is a relationship between teachers' understanding of the NOS and classroom practice. The sample in the study had different teaching experience and academic qualifications. The study revealed that teachers' opinions about the NOS are not influenced by their classroom practice and curriculum experiences. Moreover, their level of academic background is not related to their understanding of the NOS. The author also claimed that the teachers' understanding of the NOS does not necessarily influence that of the students. Of greater importance is the teachers' experience, knowledge in the subject matter they teach, and the strategies they use to make science understood in the classroom. Factors which hinder imparting of understanding of the NOS to students have also been identified. These include

the pressure to complete the syllabus, classroom management (mainly for beginning teachers), time limitations, the students' academic level and motivation, the teachers own superficial knowledge and beliefs about the NOS, lack of agreement about what constitute the required NOS contents and no proper pedagogical tools, methods and training for the teachers to teach and transfer the NOS understanding to the students.

Often, even the most experienced teachers argued that the NOS is too complex, abstract and time consuming to be taught to students. More emphasis and importance is given to science content. According to the teachers, students need to be armed with the required scientific knowledge needed either for them to pass their exams or for further studies in the scientific field (Hipkins *et al.*, 2005). In some rare cases the teachers do mention that the teaching of NOS forms an integral part of the science contents. It provides students with enough scientific information and background knowledge to make more informed decisions about science in the society. Its inclusion in teaching will therefore result in science being more interesting and comprehensible (Abd-El-Khalick *et al.*, 1998).

3.3 Summary

Researching and developing students' understanding of the NOS has been one of the main objectives of science education (Lederman, 1992). The main outcome of the different studies is the design of new teaching strategies and reform to the traditional science curricula which presently are based mostly on knowledge of contents and methods. Hence, the design and implementation of a new science curriculum is crucial. It can be made possible only if the different protagonists involved in the teaching of science and designing of science curricula reach a general consensus about the incompetencies and imperfections of the present science curricula. However, it must be ascertained that the use of the new science curriculum will not hinder the desirable science content development of those students who wish to pursue further studies in the scientific domain (Hipkins *et al.*, 2005).

At secondary level (Driver *et al.*, 1996), tertiary level (Ryder and Leach, 1999) and even for science teachers (Lederman, 1992), it is argued that for an effective development of the

understanding of NOS, an explicit teaching approach should be adopted in introducing the epistemology of science.

4. Method

Various studies have been carried out over the years to investigate people's (students, teachers and the general public) understanding and conception of the different aspects of the nature of science and more recently, on students' views on measurements when "doing" science. The most common and traditional tool used in such research is the written questionnaire, which is often followed up with interviews. In some rare cases, only interviews are conducted. However, many of these instruments have been criticized for their validity and reliability, which Redish (2003) defines as "...should measure what it claims to measure" and "...should give reproducible results" (p. 96), respectively.

The written research instrument designed for the present study was administered on two groups of first year physics students at the University of Cape Town, "mainstream" and "GEPS" students. These two cohorts of students were chosen for the following reasons:

- they were easily accessible;
- they had different academic backgrounds thereby providing opportunities for a diversity of response data; and
- earlier complementary studies were on similar samples at the University of Cape Town, thereby providing further opportunities for comparison and contrast.

4.1 Format of the VASM questionnaire

For the present study, the relationship between views of the nature of science and nature of scientific measurement is being investigated. It was decided to use, ideally a written questionnaire together with individual interviews to collect the data for this project. Many advantages are associated to the use of questionnaires for data collection in quantitative and qualitative research (Gillham, 2000). Firstly, they are quick and relatively cheap to administer. Substantial information can be gathered from a large group of participants in a short period of time. Questionnaires are usually completed anonymously. Respondents are therefore more willing to provide detailed and “honest” explanations about the items being discussed. The use of questionnaires ensures uniformity in the number and quality of questions probed. The risk of an interviewer influencing participants’ responses is also reduced. Furthermore, with a written questionnaire, there is the possibility of choosing and probing only those areas of interest for the study. There is a higher probability for the responses provided by the participants to be to-the-point and relevant to the context and purpose of the study (Leach *et al.*, 1997). However, questionnaires may have limitations since it cannot be known with certainty whether the questions were answered in the prescribed sequence. There is the possibility of misinterpretation whereby the participants’ language sophistication may affect their understanding of the words used in the items. Finally, the participants may find it difficult to express their views in writing about the issues under consideration (Gillham, 2000).

Consequently, there are many benefits for the use of individual interviews after administering a questionnaire. Individual interviews allow for the clearer determination of the students’ views on issues being explored and the underlying reasons for adopting these beliefs. The interviewer has the opportunity to probe deeper in the participants’ ideas and gather more elaborate responses for the questions, thereby reducing the risk of misinterpretation. Unclear or ambiguous responses can be clarified immediately. It is easier for students to articulate their views verbally rather than transferring their ideas in writing. Interviews help in creating profiles which can help to provide a detailed description of the participants’ conceptions about the topic under consideration (Lederman and O’Malley, 1990; Lederman, 1992; Oppenheim, 1992; Cohen *et al.*, 2000).

For the present study, the use of interviews was ruled out. It was not practical to perform individual interviews with all students as a total of 179 participants were involved. Group interviews and observations were not suitable alternatives since the research question was geared towards probing individual views about the NOS and nature of scientific measurement. Group interviews and observations are equivalent to group discussions in the fact that some respondents will be more prominent which may encourage less participation from other members in the group. Hence, there is the need for an experienced and competent interviewer to conduct group interviews. Furthermore, a limited number of questions can be probed as group interviews are time consuming. There is also the possibility of bias as participants may review their responses during discussions with other group members. Confidentiality is not easily assured in group interviews (Patton, 1990; Oppenheim, 1992).

4.2 Design of the VASM questionnaire

The research instrument, the VASM (Views About Scientific Measurement) questionnaire was designed for the present study. It contains a combination of NOS and measurement questions (probes), some of which were modified from instruments used for earlier studies. The questionnaire consists of fourteen probes, eight of which deal with views of scientific measurement and six with views of the NOS.

4.2.1 The nature of science probes

The NOS probes were designed based on the seven criteria which define an adequate understanding of the NOS as developed by Lederman (1992). The VASM questionnaire contains six probes covering certain aspects of the NOS which are of interest for the present study: views on the origin of scientific knowledge; its objective, subjective, empirical and/or tentative nature; the process used for its acquisition and construction; the relationship between scientific experiment and theory; the role of scientific experiments in a scientific endeavour; and the use of creativity and the scientific method during an experiment. Two of the NOS probes, namely probe 1 and probe 7, were adapted from other

instruments. Probe 1 was derived from Moss *et al.* (2001) and focuses on the nature of the scientific enterprise and scientific knowledge. Probe 7 was adapted from the VNOS- Form A, designed by Lederman and O'Malley (1990), where the role of creativity and imagination during an experiment is explored.

The purpose of the six NOS probes which make up the VASM questionnaire is outlined as shown by Table 4 below. The NOS probes in the VASM are designed and sequenced in logical order to allow for a natural flow in the explanations given.

Table 4: Purpose of each of the NOS probes in the VASM questionnaire.

Probe number.	Purpose of the NOS probes.
1	<p>To explore the students' views on the nature of scientific knowledge. The qualities that distinguish scientific knowledge from other forms of knowledge are probed. The responses gathered are grouped according to the following aspects:</p> <ul style="list-style-type: none"> ○ the characteristics of scientific knowledge which include the tentative, subjective and objective nature of scientific knowledge and the presence of experiments, evidence, theories/laws, equations and observations. ○ the purpose of scientific knowledge, for example, to understand, describe or explain the behaviour of nature.
2	<p>To investigate whether laws/theories are inventions of the scientist or whether they already exist in nature, waiting to be discovered. In other words, views on the origins of laws and theories in science are explored.</p>
3	<p>To probe students' views on the relationship between scientific experiments and scientific theories, in order to determine which one of these two entities has greater priority in the acquisition, construction and evolution of new scientific knowledge.</p>
4	<p>This is an open-ended question. It deals with the role of scientific experiments in the scientific endeavour. It aims at probing whether the reliability and validity of scientific knowledge is dependent on scientific experiments only and whether they always yield genuine, faultless results.</p>
7	<p>To explore the role of the scientific method and the creativity of the scientist when doing an experiment.</p>
13	<p>To investigate the actions and decisions of scientists when theoretical and experimental results are in conflict. The relationship between a scientific experiment and a scientific theory is explored.</p>

4.2.2 The nature of scientific measurement probes

The measurement section is made up of eight questions. They aim at exploring the difference between “everyday” and scientific measurements, the meaning of the term “exact”, whether or not a “true” value exists, together with the decisions made when collecting, processing and comparing data. Six out of the eight measurement questions, namely probes 8, 9, 10, 11, 12 and 14, were adapted from the “Physics Measurement Questionnaire” and “Laboratory Procedures Questionnaire”, validated in earlier studies on measurement (Allie *et al.*, 1998; Buffler *et al.*, 2001; Lubben *et al.*, 2001). The remaining two probes, 5 and 6, were newly conceptualised for the VASM questionnaire. The measurement probes are also related to one another and sequenced accordingly. Table 5 provides an overview of the main purpose of each of the measurement probes.

Table 5: Purpose of each of the measurement probes in the VASM questionnaire.


Probe number.	Purpose of the measurement probes.
5 and 10	To probe students’ ideas during the data collection phase of the measurement process. The students’ views on a single and multiple measurements are explored.
6	It is subdivided into four options. It explores whether students have a different approach to the measurement process in scientific and “everyday” contexts, the possibility of having an “exact” result in each case and the meaning attributed to the word “exact”.
8, 9 and 11	These three questions deal with data processing. The actions and decisions of students when taking measurements from digital and analogue scales are investigated together with how data from a set of multiple measurements are used to present a final result.
12	This probe deals with data comparison probe. The actions and reasoning of participants when comparing two sets of data obtained from the same experiment are explored.
14	The last question investigates students’ views about the existence of a “true” value in measurement.

4.2.3 Structure of the VASM questionnaire

Figure 4 depicts one of the probes in the VASM questionnaire. In this case, the origins of scientific laws and theories are being discussed. All the probes in the questionnaire are based on the same context which involves taking measurements for the Earth magnetic field and comparing these measurements with theories about the composition of the Earth. The majority of the probes in the VASM questionnaire follow the same style. Each probe presents a scenario followed by a number of different options. The options are presented in the form of conversations and the participants are requested to select only one of the alternatives provided, which according to them, is most appropriate. They are also asked to give a detailed written justification for their choice. Sufficient space is provided for the participants to write their responses in full. The explanations which they provide represent their decisions, the underlying reasoning on which their actions are built.


2. You now think about what scientists do.

Nature follows exact laws and scientists discover these laws.




A

No, scientists construct theories to explain what they observe in nature.



B

I have another view which I will explain.



C

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

A	B	C
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Explain you choice.

Figure 4. Example of an NOS probe from the VASM questionnaire.

Cartoons were used and labelled by letters A, B, C or D to present the various options. From the studies previously carried out on measurement at the University of Cape Town (Allie *et al.*, 1998), it was found that the use of real life figures and names can lead to prejudice towards the selection of an option. Consequently, cartoons were used in the questionnaire as they do not refer to any specific gender, race and culture.

Special attention was given to the language used to frame the items. The vocabulary was chosen to be simple and the words were reduced to a minimum. The order of the probes is also crucial since the concepts explored in each question should follow a logical order, and the probes should not provide any hints about the questions which follow.

For the main study, no interviews were carried out after completion of the VASM questionnaire. The need for interviews was compensated by requesting a detailed explanation in each of the probes. The request for an explanation is important for the following reasons:

- firstly, it ensures that the selection of words used in the questions was understood by the students;
- it reduces the risk of the researchers misinterpreting the views of the students; and
- it allows the participants to be reflective about their own views.

Furthermore, by providing the option “I have a different idea” or “I have another view which I will explain” in some probes, respondents are encouraged to express their own opinions on the issues discussed in the probe.

4.3 Piloting of the VASM questionnaire

The views displayed about science depend on the scientific domain under discussion because students’ responses may vary for different scientific contexts (Ryder and Leach, 2000). For our study, the questionnaire was designed to probe first year students’ views on the NOS and the nature of scientific measurement in a physics context. The final version of

the VASM instrument was obtained after several rounds of pilot testing with reflective discussion of the test items. The purposes of the pilot tests were:

- to check the validity of the data collection instrument and whether appropriate words were used in the questions such that they were understandable to the majority of the participants;
- to check the validity of the analysis and whether the method of analysis was suitable for the purpose of the study; and
- to verify whether the sequence of the probes was appropriate and enough time was allocated to complete the questionnaire.

4.3.1 Student samples used in the pilot tests

An early version of the VASM was completed by 11 physics honours students from the University of Cape Town, and 38 undergraduate first year science students from the Cape Technikon. The latter participants are majoring in different technical courses but take physics as an elective.

These cohorts were chosen because of their easy availability and represent different levels of science understanding. The postgraduate sample represents a “sophisticated” group since they are actively involved with hands-on experimental work. The Cape Technikon students were chosen because their academic and science backgrounds are similar to the students included in the main study for the present work. Class discussions were conducted with the Cape Technikon and honours students, immediately after the completion of the questionnaire. From the discussions, it was apparent that most of these students found the probes to be understandable and it appeared that there was no misinterpretation of ideas or words.

4.3.2 Modifications due to piloting

Analysis of data from the pilot tests led to the adjustment of several of the items in the VASM.

(a) Open-ended questions

When alternatives were provided for three of the probes (1, 4 and 9) dealing with the nature of scientific knowledge, the purpose of a scientific experiment in a scientific endeavour and taking a reading from an analogue scale, respectively, participants tended to rephrase the text in the probe when justifying their actions. An example, from probe 1, illustrates this case:

You and a group of friends are discussing your views on what science is.

A: Science is about the quest for the absolute truth.

B: No, science is a tool for understanding what we observe in nature.

C: I have another view which I will explain.

The chosen option is B and the quotes which follow highlight the written explanations given:

Science is a tool we use to try and understand nature.

Science is the understanding of nature.

These three particular probes were thus designed to be open-ended. For illustration purposes, below is the example for the new version of probe 1:

You and a group of friends are discussing your views about the nature of **scientific knowledge**.

You wonder what makes certain types of knowledge “scientific”?

(b) Misinterpretation of statements

In some probes, the words used led to misinterpretations. An example is from probe 3:

You now think about what happens when scientists do an experiment.

A: The advance of science always relies on results from scientific experiments.

B: No, I disagree.

The chosen option is B and the responses below exemplify the explanations provided:

Advances in science also relies on natural phenomena and purely on experimentation. Additionally the social, political and contextual influence on scientific advances should be taken into account.

The advances of science do not always rely on scientific experiments but its interaction with society.

In this probe, the interplay between theory and experiment is being investigated. However, it was interpreted by the students as the progress of science being dependent on many factors including issues around society, culture and politics, which are irrelevant in this context. Probe 3 was consequently reformulated by making use of the appropriate words in order to convey the intended ideas.

The new version of probe 3 reads:

You continue to think about science.

A: New scientific knowledge is based on the results from scientific experiments.

B: No, new scientific knowledge can result from existing scientific theories.

C: I have a different idea.

4.4 Final version of VASM for main study

The full version of the VASM questionnaire is presented in Appendix 1. It was completed by 179 first year physics students from the University of Cape Town, during the first semester of 2005, before instruction from their physics course.

4.5 Sample in the main study

4.5.1 Mainstream students

The mainstream group comprised of 64 first year science students in the PHY104W course who were taking physics either as a major or an elective as part of their three year Bachelor of Science Degree. In general, their age group varied from 18 to 21 years old with English as their home language. These mainstream students generally have a good academic and science background and have intensive hands-on experience with practical work at school.

4.5.2 GEPS students

The second category of participants in the sample was made up of 115 first year science students registered for PHY123H. It is a core course in the General Entry for Programmes in Science (GEPS) which forms part of a four year structured Bachelor of Science degree programme at UCT. The majority of these students have an age group varying from 17 to 21 years old, come from socio-economically disadvantaged backgrounds and speak English as their second language. In contrast to the mainstream students, this cohort generally had poor science teaching at school with superficial or no prior experience with experimental work. In many cases, their school was not equipped with a proper laboratory and they had to be transported to other institutions to perform those experiments which were examinable as part of the school science syllabus.

4.6 Administration of the VASM questionnaire

The VASM questionnaire consists of 16 pages (see Appendix 1). Fourteen of these pages are concerned with the probes, each question appearing on a separate sheet, and the remaining two pages deal with requesting the background of the students, their personal and school details, together with their impressions about their science laboratory course at school. The instruction sheet is glued onto an A4 envelope. Each envelope and its contents

were stamped with a unique number to facilitate the identification of the students during later analysis. The probes were placed in correct order in the envelope and handed to each participant. They were required to write their name and student number in the space provided on the instruction sheet on the envelope, and to read the instructions carefully before starting the questionnaire. They were then requested to remove all the sheets from the envelope, not to look ahead through the different probes and answer all the questions individually, in strict sequence, making sure not to skip any sheets. Once an answer sheet was completed, it was placed back in the envelope and not reviewed. In addition, the students were asked not to erase any of their responses but to add any new ideas below the old ones. Hence, they are prevented from looking back on previous probes to modify their answers. The respondents were allocated an average of five minutes to answer each question. This time was found to be enough for the respondents to be reflective about their actions and give a complete and detailed explanation for their views.

The whole process was done under examination conditions. The GEPS students completed the task as a compulsory assignment during their first scheduled afternoon laboratory session. The mainstream students completed the questionnaire during one of their afternoon tutorial sessions.

4.7 The coding scheme for the probes

An alphanumeric coding scheme for the probes was designed for this study. The scheme consists of codes which are made up of a letter corresponding to the chosen option (the action) and a two digit number representing the underlying reason (decision) given to support the action. The first digit represents the main category of decision, while the second digit refers to the various sub-categories of reasoning.

Figure 5 provides a representation of a code used in the coding schemes.

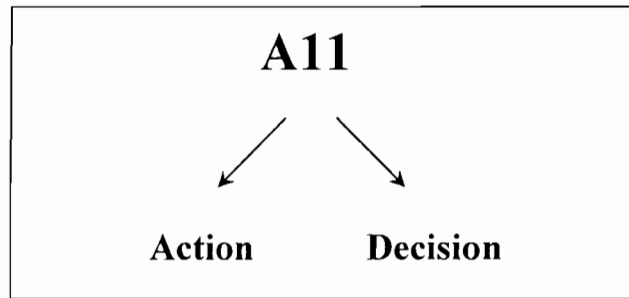


Figure 5. Representation of a code in the coding schemes.

The codes for decisions provided for probes 10, 11 and 12 of the measurement section, were taken from those designed for earlier studies on measurement (Buffler *et al.*, 2001). For the remaining probes, either on measurement or on the NOS, a grounded theory approach (Strauss and Corbin, 1990) was used to design the coding scheme. This method involves starting with the aim of the study, reading and reviewing the data from the different probes which are then analysed and converted into different sets of recurring “statements”. These statements are then grouped according to similarities in underlying concept. The grounded theory approach limits the risk of prejudice and assumptions on the part of the researcher as the categories in the coding schemes are generated from the participants own responses and are hence representative of the main ideas enclosed in the data. The validity of the coding scheme was checked by two researchers who independently generate codes from the responses. The codes were then compared and discussed, and an agreement was reached on the arrangement and grouping of the codes according to their mutual exclusivity and logical hierarchy.

The coding scheme, for the measurement and the NOS sections, follows the pattern as shown in Figure 6, which depicts, as an example, the coding scheme for probe 2.

2. You now think about what scientists do.

N00 – No response

U00 – Not able to code response

	Frequency of codes	
A		Nature follows exact laws and scientists <u>discover</u> these laws because...
A00	1	(no reason given)
A01	10	(not able to code response given)
A10	23	nature already has its laws/rules. Scientists have to research/prove and explain them.
A11	-	science deals with facts
A12	-	science is about what is observed in nature.
....
A40	-	scientists help to improve the world/find solutions to problems
....
B		No, scientists <u>construct</u> theories to explain what they observe in nature because...
B00	2	(no reason given)
B01	10	(not able to code response given)
B10	12	nature already has its laws/rules. Scientists have to research/prove and explain them.
....
B32	10	scientists experiment on what they observe and then formulate laws/theories on what will explain nature.
...
C		I have another view which I will explain.
C00	-	(no reason given)
C01	2	(not able to code response given)
C10	6	Nature already has its laws/rules. Scientists have research/prove and explain them.
....
C50	1	Scientists model nature.

Figure 6. An abridged version of the coding scheme for probe 2.

The coding scheme for each probe is separated into various headings according to the chosen option. These groups are further subdivided into categories (A10,..., A40) each representing a distinct view for each option. Each cluster has a code (for example A10) which represents the main idea expressed for a chosen option together with subsequent codes (A11, A12,...) which allow for sub-categories. Responses which are irrelevant are

given the code U00 and when no explanations are provided, the code N00 is allocated. The “Frequency of codes” column represents the number of student responses attributed to the different codes, in the coding scheme, for a particular probe.

From the previous studies carried out to investigate first year physics students’ views on measurement at the University of Cape Town, it was found that the style of the coding scheme described above was a useful tool to facilitate the description of the views of the students expressed in the probes. In this study, the coding scheme facilitates the identification and classification of both the actions and decisions of each student expressed in the probes. It is also flexible such that new responses which do not fit any of the existing categories in the scheme can be added. Moreover, the reason given for an action may not necessarily be limited to the chosen option only but can be formulated for any one of the alternatives presented in the particular probe. For example, one student may be allocated the code A10 and another student choosing option B may display the same reasoning represented by the number 10 such that the code allocated is B10.

4.7.1 Coding of the responses

The coding of the responses for the mainstream and GEPS samples were completed separately. The probes were first sorted into sets of the same question, in order to facilitate the coding process.

The response of each student for a particular question was assigned a code according to the alphanumeric coding scheme. The chosen option (A, B, C or D) was first considered followed by the category of decision which was selected from the different options in the coding scheme. A code was allocated by considering the underlying idea of the response provided by the students and comparing it with the responses in the coding scheme. Hence, more importance was given to the reasoning rather than the chosen option of the respondent.

After coding all the responses, the codes allocated to the probes, for the GEPS and mainstream groups, were then captured on a spreadsheet, as illustrated in Figure 7.

Student number	Q1.	Q2.
Number stamped on the envelope and probes in each set.	Code allocated for each measurement probe.				

Figure 7. Representation of how the codes were captured in the spreadsheet.

The first column of the spreadsheet lists the numbers stamped on the envelopes and probes allocated to each student. The other columns list the codes assigned to the different responses for each student. The codes for each of the probes were then sorted and clustered according to similarities in the ideas expressed, for further analysis.

5. Analysis

The analysis of the measurement and NOS probes was carried out differently and separately. In the presentation below, an abridged version of each probe is presented together with a statement of the purpose of each probe. The different views of the participants from each cohort, together with the respective frequencies of the types of responses are tabulated. For the probes dealing with measurement, the classification of the responses according to the point and set paradigms are provided, represented by the abbreviations P and S, respectively. The full version of the coding scheme for each probe is provided in Appendix 2. A selection of the students' written responses either from the mainstream or the GEPS group are used, verbatim, to illustrate the different types of responses to each probe.

5.1 Ideas about measurement

The measurement responses of the participants were categorized as point or set paradigm according to the criteria which characterize them as developed from earlier studies by Lubben *et al.* (2001). Reference was made to the participants' reasoning in their responses to the different measurement probes as a basis for deciding the appropriate code and its association with either the point or the set paradigm.

5.1.1 Probes dealing with data collection

Probe 5 and 10 are concerned with the data collection stage of the measurement process. The participant's views on single and multiple measurements are explored.

(a) Probe 5

The text of probe 5 is as shown below:

You continue to think about scientific measurement.

A: Sometimes only one scientific measurement is sufficient for an exact result.

B: No, for a scientific measurement result to be exact, the experiment needs to be repeated many times and the average calculated.

C: I have another idea.

Table 6 provides an overview of the GEPS and mainstream participants' responses for probe 5.

Table 6: Responses of the GEPS and mainstream participants for probe 5.

Paradigm	Response type	Codes	GEPS	Mainstream
P	Multiple measurements lead to more accurate values and hence confirm the final result.	C40; B44; B45; C45; B47; C47; B48.	39 (34%)	20 (31%)
P	Multiple measurements are taken to check whether the same value is obtained.	A41; B41; C41; B42; C42; B43; C43.	25 (22%)	3 (5%)
P	Multiple measurements lead to the removal of errors.	B46.	7 (6%)	4 (6%)
P	Multiple measurements are required to calculate the average which is closer to the true or the required value.	B62; C62; B66.	1 (1%)	7 (11%)
P	The number of measurements to be taken depends on the type of experiment.	A20; B20; C20.	6 (5%)	1 (2%)

P	Repeating readings is a waste of time.	A30; B30; A31; C31; A32.	5 (4%)	1 (2%)
P	Measurements must be repeated.	B49.	1 (1%)	- (0%)
S	Multiple measurements are required to calculate the average which gives a more accurate value.	B61; C61; B63; C63; B64; C64.	15 (13%)	18 (28%)
S	All experiments or measurements have inaccuracies or errors.	C70; C71; B72; C72; B73; C74; B75; C75.	8 (7%)	6 (9%)
S	Multiple measurements are needed to provide a more accurate value together with its uncertainty.	C80	- (0%)	2 (3%)
-	Not able to code response.	U00	8 (7%)	2 (3%)
Total			115 (100%)	64 (100%)

The majority of the respondents use reasoning associated with the point paradigm (84 in 115, 73% for the GEPS group, and 36 in 64, 57% for the mainstream cohort). They believe that repetition is necessary to see if the same value is obtained, or to select the recurring measurement. Consequently, the result obtained will be more accurate and reliable. The responses below exemplify these decisions:

It is necessary to repeat an experiment many times to ensure that the same result is obtain in all experiments. By repeating the experiment you can ensure that no mistakes have been made. (267)

For exact results for a scientific measurements the experiment should be repeated and take the answer which comes many times. (301)

If only 1 measurement is taken it is possible a mistake could have been made or something like that. The more it is repeated the more accurate it will be. (260)

Some students claimed that the repetition of measurements will lead to a reduction of errors associated with the data. A student gave the following written statement:

I agree with B because repetitions clear out some small errors. (399)

In a few cases, as illustrated by the different quotes below, multiple measurements are considered a waste of time. The need for many readings is dependent on the type of experiment being conducted.

If I am trying to find if the gravitational force acts on a certain object, and this object is being dropped and does fall to ground, then I do not need to repeat this experiment. (258)

I think sometimes only one scientific measurement is sufficient for an exact result cause all we have to do is to perform/do that measurement correctly. Make sure that everything is put in order before measuring that will be sufficient for an exact result. But sometimes you'll have to do it again to make sure. (300)

In contrast, students whose decisions are associated with the set paradigm argue that measurements always involve some degree of inaccuracies. Multiple measurements are thus needed to calculate the average value which reduces the margin of error and hence yield a better result. Samples of responses which highlight these ideas are presented below:

When many measurements are taken and the average calculated, it reduces the possibility of errors in the measurement. Also, one can observe under what conditions exceptions to the hypothesis may be found. (276)

Although repeating an experiment and calculating the average of many results gives a more valuable result, (since it reduces experimental error and the chance that the measurement was very inaccurate), the results of an experiment cannot reveal a result which is completely exact. (273)

Under varying conditions the outcomes of the some scientific measurements could change (eg: humans cannot see precisely on measuring equipments) so to allow for a fair degree of accuracy, the measurements should be re-calculated several times and an average taken. (342)

(b) Probe 10

Probe 10 which also deals with data collection reads as follows:

You see that the scientists discuss what to do after taking one measurement of the magnetic field. You wonder whether or not they need to repeat their measurement.

A: I think that the scientists should repeat their measurement of the magnetic fields a few times.

B: Why? They have their result already. They do not need to repeat the measurement.

C: I think that the scientists should repeat their measurement one more time.

The categorised responses during the data collection stage of the measurement process are summarised in Table 7.

Table 7: Responses of the GEPS and mainstream participants for probe 10.

Paradigm	Response type	Codes	GEPS	Mainstream
P	Multiple measurements lead to more accurate values and hence confirm the final result.	A20; C20; A21; A24; C24; A36.	45 (39%)	23 (36%)
P	Multiple measurements are taken to check whether the same value is obtained.	A40; C40.	28 (25%)	10 (15%)
P	Multiple measurements lead to the removal of errors.	A23.	6 (5%)	5 (7%)
P	Multiple measurements lead to the true value.	A22; A25.	6 (5%)	3 (4%)
P	Measurements must be repeated.	A60.	4 (3%)	1 (2%)
P	Repeating readings is a waste of time.	B51; C51.	4 (3%)	- (0%)
P	Multiple measurements are required to calculate the average which is closer to the true or the required value.	A34.	3 (3%)	1 (2%)
P	Repetition is needed for practice.	A10	1 (1%)	- (0%)

S	Multiple measurements are required to calculate the average which gives a more accurate value.	A30; A31; A35.	15 (13%)	19 (30%)
S	All experiments or measurements have inaccuracies or errors.	A80; A50.	2 (2%)	1 (2%)
S	Multiple measurements are needed to calculate the uncertainty value.	A70.	- (0%)	1 (2%)
-	Not able to code response.	U00	1 (1%)	- (0%)
Total			115 (100%)	64 (100%)

The types of responses provided by students for the probes 5 and 10 dealing with repeated measurements are similar. In probe 10, an even larger majority of the students use a point paradigm (97 in 115, 84% of the GEPS students and 43 in 64, 67% of the mainstream students). Respondents emphasise the need for multiple measurements to either check whether the same value is obtained or whether the readings gathered are close to one another. Repetition thus acts as a confirmation of the result. The final value obtained becomes more accurate as the errors associated with the measurements have been completely reduced to zero. Typical explanations which represent these views are shown below:

The only way they can be sure is if they repeat it a number of times. If they got the same value each time then they can be sure and if they don't get the same value then something is not right. (263)

They need to make sure their measurement is accurate and by measuring multiple times they may notice a pattern of some sort. (236)

It is necessary to repeat the experiment a couple of times in order to eliminate human errors, and gain more certainty of the result of the experiment. (216)

The more one repeats an experiment the more accurate the result is and the better the result can be trusted for further study. (361)

In one case, it was stated that values which are close to one another must first be selected from the series of readings followed by the calculation of an average value. This category of reasoning was also classified according to the point paradigm. The student wrote:

Repeating the measurement a few more times determines the accuracy of the results. The results can be compared and the best approximate amounts chosen. The best way is to find the average of a few put together to find out the nearest or even exact answer. (302)

Explanations given for probe 10 which are categorised according to the set paradigm include the need for multiple readings in order to calculate the average value which increases the accuracy of the result, and the fact that measurements always have errors which can never be reduced to zero. Examples of responses which describe these views are shown below:

Doing it once or twice is less accurate than doing it a few times and calculating an average. Therefore by calculating an average they can arrive at a more accurate answer. (348)

To say that the result was accurate they would have to take a few readings. One could argue that the instrument would not give a different result a second or third time. However, to reduce the possibility of errors an average must be take. (276)

As can be seen from the examples above, it may be concluded that the students' beliefs in the role of repeated readings given in probes 5 and 10 are consistent with one another. Priority is given to taking repeated measurements either to obtain values which are close to one another or to confirm the final result. Furthermore, by taking multiple measurements, the value which appears most frequently can be selected. However, it was acknowledged, by a quarter to a third of the respondents, that repeated measurements are needed to calculate the average which reduces errors associated with the readings and hence increases the accuracy of the final result.

5.1.2 Probe dealing with scientific and “everyday” measurement

Probe 6 investigates whether science students have a different approach to the whole measurement process in the scientific and “everyday” domains.

You now think about whether or not there is a difference between scientific measurements and measurements made in everyday life (for example: weighing the mass of a chemical produced in a chemistry experiment, compared to weighing some flour required for baking a cake).

A: Both scientific measurements and everyday measurements can be exact.

B: I think that scientific measurement can be exact, but everyday measurements are never exact.

C: No. Both scientific measurements and everyday measurements are never exact.

D: I have a different idea.

Table 8 presents the different ideas used by the respondents when dealing with data in the scientific and “everyday” contexts.

Table 8: Responses of the GEPS and mainstream participants for probe 6.

Paradigm	Response type	Codes	GEPS	Mainstream
P	Highly sophisticated and sensitive apparatus is used for scientific measurements.	A10; A11; D11; A12; B12; D12.	24 (21%)	7 (11%)
P	Scientific measurements are usually more precise than “everyday” measurements which are rough estimates.	B41; C41; A60; D60; C61; D62; A70; B70; C70.	21 (18%)	17 (27%)
P	In science, “exact” values are required as the scientific endeavour must be successful.	D22; D23; A80; B82; D82; A84; B84; D84; A86.	17 (15%)	1 (1%)
P	The “exactness” of a measurement depends on the methods and skills used to perform an experiment and collect data.	A71; B71; D71; A87; D87.	9 (8%)	6 (9%)

P	In science, only a value close to the true value can be obtained.	A30; C30; B33; D33.	- (0%)	4 (6%)
S	Measurements always have inaccuracies. Hence, only the best approximation can be obtained.	A31; D31; A40; C40; D40; C42; D42; C43; C44; C45; D88.	27 (23%)	26 (41%)
-	Multiple measurements are required.	A50; C50; B55.	7 (6%)	- (0%)
-	Not able to code response.	U00	10 (9%)	3 (5%)
Total			115 (100%)	64 (100%)

Again, a large proportion of students use a point paradigm, 71 in 115 (62%) of the GEPS students, and 35 in 64 (55%) of the mainstream students. Students categorised according to the point paradigm deal with the measurement process differently in the two contexts. Scientific measurements are thought to be more “exact” than “everyday” measurements with reasoning based on the type of instruments or the procedures used to gather the measurements. Quotes which represent the underlying ideas outlined above include:

Scientific measurements are exact because right equipments are used and everyday measurements are merely approximate measurements that a person makes. (310)

Scientific measurements will be more accurate than everyday measurements because of the advanced technology present in a laboratory. Scientists are very precise and accurate people compared to those who make everyday measurements. (319)

They can be exact both of them but it will depend only on how they were conducted. For example if the correct steps were followed and the laws were obeyed for that scientific experiment(s), the result would be exact. (286)

Scientific measurement must be exact, the wrong measurement could result in a different end product. In everyday measurements the rules are not that strict, there is more room for a slight error. (364)

Scientific measurements must be exact for the proper results in an experiment. It will not spoil the cake if the flour is not weighed. (306)

In contrast, responses are associated with the set paradigm if reference is made to the notion that scientific and “everyday” measurements can never be exact because in both situations there are bound to be some inaccuracies or errors. These students appear to treat the whole measurement process in a similar way in the two situations. In both cases, a measurement is seen to provide an approximate value. Either the “exact” value does not exist or it cannot be achieved in the scientific and “everyday” domains, with the result that only a value close to the “exact” value can be obtained. The following explanations, as provided by the participants, justify these decisions:

Exact is giving a measurement correct to every significant figure i.e when giving the mass, one needs to account for the mass of every atom or other source of mass in the thing one is weighing. This usually impossible to do. (203)

No measurement is ever 100% exactly correctly. It is simply not possible to be accurate to degrees of extremely small nature. The measurements may, however, be accurate enough for our purposes in any given situation. (231)

Exact measurement are never produced in any environment. They can be close to exact but never exact. (262)

To summarise, those students whose beliefs are consistent with the point paradigm provided various reasons to explain the distinction between scientific and “everyday” measurement. In science highly sensitive apparatus are generally used for taking measurements, while “everyday” measurements are only rough estimates. There is the need to be accurate and successful in science as the results will be used for improvements either in the investigation performed or in everyday life. Respondents whose decisions were classified according to the set paradigm handle the measurement process similarly in both contexts. In general, measurements have inaccuracies which can never be completely reduced to zero with the result that the final value obtained will be an approximation to the “true” value. Moreover, relatively large proportions of the responses to this probe could

not be classified as using either a point or a set paradigm (17 in 115 for the GEPS cohort and 3 in 64 for the mainstream group). This may be a consequence of the complexity of the probe as it asks for a comparison.

5.1.3 Probes dealing with data processing

Three probes, namely 8, 9 and 11, deal with data processing. Probes 8 and 9 involve taking a reading from a digital and analogue scale, respectively. In probe 11 participants are presented with five readings and have to decide on how to use them to give a final result.

(a) Probe 8

The text for probe 8 reads:

The scientists now start taking measurements. They first use a **very sensitive instrument** with a digital scale to measure the Earth's magnetic field. What is seen is shown below.



You discuss what the scientists now know about the Earth's magnetic field.

- A:** I think that the scientists now know the Earth's magnetic field is exactly 0.137 mT.
- B:** I think that the scientists only have an approximate value of the Earth's magnetic field.
- C:** I don't agree with either of you.

Table 9 summarises the actions and decisions of the sample when taking a measurement from a digital scale.

Table 9: Responses of the GEPS and mainstream participants for probe 8.

Paradigm	Response type	Codes	GEPS	Mainstream
P	Only one measurement is available. Multiple measurements are needed.	B31; C31.	22 (19%)	11 (17%)
P	A highly sophisticated apparatus is used.	A10; B10; C10; A12; A16.	21 (18%)	- (0%)
P	Multiple measurements are needed to check whether the same value is obtained.	C32; A34; B34; C34.	7 (6%)	- (0%)
P	Only values close to one another can be obtained.	B35; B60; C62.	5 (4%)	1 (2%)
S	The apparatus and the measurement process used always have inaccuracies.	B13; B15; B30; B50; B51; B52; C52; B53; C53; B54.	37 (32%)	36 (56%)
S	The value has been rounded off.	B40.	9 (8%)	4 (6%)
S	Multiple measurements are needed to calculate the average.	B33; C33; B37.	7 (6%)	6 (9%)
S	Only the best approximation can be obtained.	B24; B71; B72; C72.	3 (3%)	3 (5%)
S	A reading is meaningless without its uncertainty value.	B80.	- (0%)	1 (2%)
-	Not able to code response.	U00	4 (4%)	2 (3%)
Total			115 (100%)	64 (100%)

A relatively large proportion of students, 56 in 115 (49%) of the GEPS students, and 50 in 64 (78%) of the mainstream students, were associated with the set paradigm. Only 19% (12 in 64) and 47% (55 in 115) of the mainstream and GEPS students, respectively, were categorised according to the point paradigm. For this particular probe, responses are characterised according to the point paradigm if reference is made to using a highly

sophisticated apparatus which yields the exact value. A student gave the following response:

As they were using a very “sensitive” instrument there is no guessing or approximation but exactly what they see is exactly Earth’s magnetic field. There is no hesitation on that. (380)

Furthermore, multiple readings are necessary since only one measurement is available. A series of measurements give more accurate results and the value which appears most often must be selected. The responses which exemplify these views are typified by:

The scientists don’t know for sure that that is the correct measurement, the experiment should be done more than once and if that number/result comes up every time then it is the correct measurement unless they are doing it wrong. (343)

Its only the first measurement and they can’t be exactly sure if that is the right magnetic field. They need to do more experiments to confirm. (394)

The view that measurements are affected by different sources of uncertainties which include the experimental, “measuring” process or the accuracy of the instrument, is associated with the set paradigm. The need to take multiple measurements in order to calculate the average value is also categorised according to the set paradigm. Samples of quotes which describe these views are presented below:

The scientists have a value accurate to the limits of their equipment, assuming the experiment was carried out correctly. (202)

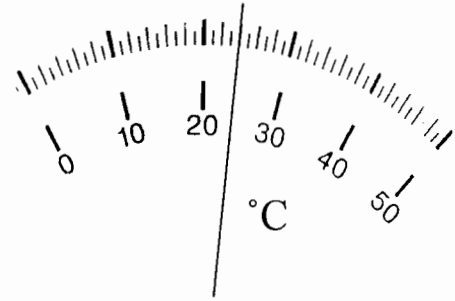
The reading meter is firstly man-made which is bound to have small errors and secondly the meter only shows up to 4 significant figures and therefore the field could be slightly larger if more decimals were shown so therefore only approximate. (209)

This is very likely an approximate measure, as this is only their first measure, they will surely take many more readings and later work out an average. (212)

(b) Probe 9

Probe 9, where a reading is taken from an analogue scale, is summarised below:

The scientists also need to know the temperature in the laboratory. They use a **special thermometer** and what they see on the display of the thermometer is shown. What is the temperature in the laboratory?



The various views expressed when taking a reading from an analogue scale are provided as shown in Table 10.

Table 10: Responses of the GEPS and mainstream participants for probe 9.

Paradigm	Response type	Codes	GEPS	Mainstream
P	The pointer reads 24°C from the sensitive analogue scale.	A10; A11; A30.	69 (60%)	27 (42%)
P	The temperature 24°C is the ideal temperature needed for a laboratory and to perform an experiment.	A32; A41; C41; A42; A43; A44.	20 (17%)	1 (2%)
P	Multiple measurements are needed.	A80.	- (0%)	1 (2%)
S	All measurements or experiments have inaccuracies.	A60; B60; A61; B61; B62; B63.	12 (10%)	21 (32%)
S	The value read off is dependent on the accuracy of the instrument.	B12; B13; B15.	2 (2%)	11 (17%)
S	The temperature must lie within an interval.	A31; B90.	2 (2%)	1 (2%)
-	Not able to code response.	U00	10 (9%)	2 (3%)
Total			115 (100%)	64 (100%)

Most of the GEPS students, 89 in 115 (77%), were associated with the point paradigm compared to only 29 in 64 (45%) of the mainstream students with a point paradigm. The majority of the mainstream students, 33 in 64 (52%), were categorised according to the set paradigm. A response is classified according to the point paradigm when the actions and decisions are completely focused on the individual value displayed on the scale. For example, when it is mentioned that the needle is pointing on the 24 degree mark, the actual value observed on the sensitive analogue instrument should be read off, and if 24°C is suggested to be the appropriate temperature needed to perform an experiment in the laboratory. The different written statements given below illustrate these views:

The thermometer has numbers ranging from 0-50 that are divided into 10. And the thermometer level or reading is on 24 reading from left to right. (285)

That's the reading on the thermometer concerning the room temperature in the laboratory (24°C). (310)

Curiously, several responses did not seem to be determined by the measurement on the analogue scale but more by the desirable measurement, expressing a belief in a “true” value. The quotation below illustrates this view:

It should be 25°C, since laboratory is a place where there are different chemical, which they need to be kept under 25°C (room temperature). If this can be above, there can be an explosion and if this is below, they can be damage through the chemicals. So the temperature should be 25°C where they will all fit. (288)

Participants whose beliefs follow the set paradigm argue that there are inaccuracies, either in the experimental or the measurement process. These errors can never be completely eliminated. Also, the type and accuracy of the instruments used affect the readings observed. The quotes which follow highlight these ideas:

The dial on the thermometer can only be read accurately to a degree celcius, therefore my answer can only be given to that. The answer can lie anywhere between 23.5°C to 24.5°C. (203)

The above scale is graduated in degrees Celsius. It is analogue though the scale gives a definite reading of 24°C, I have said approximately 24°C, because of errors in the equipment etc. What a reading of 24°C tells us is, in fact, that the temperature in the laboratory is close enough to 24°C (bar systematic errors in the device) to be considered 24°C for ordinary purposes. (205)

(c) Probe 11

The text for probe 11 reads:

The scientists decide to repeat their measurement of the magnetic field five times. Their results are shown below.

<u>Measurement</u>	<u>Magnetic field (mT)</u>
1	0.137
2	0.128
3	0.138
4	0.128
5	0.134

You then discuss what the scientists should record as their final result for the magnetic field.

Table 11 provides an overview for the different explanations given by the samples when processing data.

Table 11: Main responses of the GEPS and mainstream participants for probe 11.

Paradigm	Response type	Codes	GEPS	Mainstream
P	The recurring value must be chosen.	A10; F11.	41 (36%)	3 (5%)
P	The values which are close to one another or to the average are selected.	B31; C40; C41; B41; D43; F45; F71; F73.	11 (10%)	8 (12%)
P	The middle value is selected.	C80; F81.	3 (2%)	1 (2%)
P	The minimum value is selected.	E90; A91.	2 (1%)	- (0%)

P	The last measurement is used. It was obtained after practising five times.	C60.	1 (1%)	- (0%)
S	The average value is calculated.	B30; C30; D30; E30; F70.	54 (48%)	47 (73%)
S	The median value is selected.	B50; C50.	- (0%)	3 (5%)
-	Not able to code response.	U00	3 (2%)	2 (3%)
Total			115 (100%)	64 (100%)

The majority of the mainstream students, 50 in 64 (78%), were associated with the set paradigm. There was a 3% difference in the percentage of the GEPS students categorised according to the point paradigm (58 in 115, so 50%) and the set paradigm (54 in 115, so 47%). The types of reasoning classified according to the point paradigm include when the recurring value is selected, when there is a focus on the individual values only, and when a value close to the “true” value is chosen. The following responses were given:

Because through their experiment this is the only number that has showed up twice and so it can be the real value for the magnetic field. (284)

Measurements one and four give out the same results so these results are more likely to be the correct results since they appear in 2 measurements. They are the results they should use. (289)

It is closest to the average of the five readings. (333)

The responses, as illustrated by the quotes below, where the final result is either represented by the average of the five measurements or by the median value, are associated to the set paradigm.

This is because this is an average of all the readings that were recorded. (211)

It is the median of all the readings. (264)

Similar reasoning was used by participants whose decisions were based on the set paradigm, when processing data from the analogue and digital scales. In all cases, the various sources of uncertainties which may affect the measurement values were considered. For probe 11, students whose decisions are classified according to the set paradigm prefer to calculate the average value.

In contrast, respondents whose views are characteristic of the point paradigm believe that only one reading is enough as the digital instrument is very sensitive. In some cases, many readings are required either to select the recurring value or to have more accurate values and hence be sure about the final result. When using the analogue instrument, the action and underlying reasoning are geared towards treating the data individually. Finally, when presented with a series of readings (probe 11), the value which occurs most frequently was selected instead of modelling the data using statistical procedures.

5.1.4 Probe dealing with data comparison

Probe 12 deals with actions and decisions when comparing two sets of data obtained from the same experiment. The text of probe 12 reads:

The scientists now decide to compare the results obtained by another group of scientists for the same experiment. The data are shown below.

<u>Measurement</u>	<u>Group A</u> <u>Magnetic field (mT)</u>	<u>Group B</u> <u>Magnetic field (mT)</u>
1	0.137	0.128
2	0.128	0.140
3	0.138	0.134
4	0.128	0.127
5	0.134	0.126
Average:	0.133	0.131

A: The results of groups A and B agree with each other.

B: No, the results do not agree with each other.

The views of the samples when comparing two sets of data from the same experiment are tabulated in Table 12.

Table 12: Responses of the GEPS and mainstream participants for probe 12.

Paradigm	Response type	Codes	GEPS	Mainstream
P	The two average values are nearly the same.	A10; B10; A11; A14; A15; B40; B41; B43.	85 (74%)	47 (73%)
P	The individual readings from the two data sets are nearly the same.	A20; B26; B60.	16 (14%)	6 (9%)
P	There are some readings which appear in both data sets.	A24; B25; A28.	10 (8%)	2 (3%)
P	The readings from both sets have the same spread.	A21.	- (0%)	3 (5%)
P	The average lies between the range of measurement obtained in group A and group B.	A44.	1 (1%)	1 (2%)
S	The measurements have an overlapping spread.	B22; A22.	1 (1%)	1 (2%)
S	The uncertainties of the averages overlap with each other.	A30; A31.	- (0%)	2 (3%)
-	Not able to code response.	U00	2 (2%)	2 (3%)
Total			115 (100%)	64 (100%)

An overwhelming number of respondents use reasoning associated with the point paradigm, 112 in 115 (97%) of the GEPS students, and 59 in 64 (92%) of the mainstream students. For this probe, an explanation is associated with the point paradigm if the data comparison process is based on the average value only or on the individual values from the two sets of data. Examples of students' written statements include:

The values recorded in each measurement by group A and group B differ, and the average of the values from all the measurements provide different answers, thus the “results” don’t agree. (271)

They have close averages which means their results agree with each other. It’s just that minor environmental conditions caused the little difference in their results. (262)

Both groups got fairly similar readings so we can conclude that the true value is near to the value that these groups obtained. (202)

I agree with group A because the measurements obtained do not differ drastically and it may be due to a number of other factors that the two groups’ measurements each time turned out differently. (368)

Reasoning which typifies the set paradigm, as portrayed by the quotes below, include overlapping of either the range of the readings or the uncertainties of the averages from each data set.

The averages obtained by both groups may differ by 0.002, but the range of their readings indicate a margin of error of ± 0.005 and ± 0.007 resp. thus each result of the two groups will lie within the range of the other showing that they agree. (225)

The average “0.131” lies in the uncertainty of 0.133 which means that 0.131 is still acceptable because anything greater than $0.133+0.005$ mT as anything greater than $0.133+0.005$ mT as anything lesser than $0.133-0.005$ mT is unacceptable. (230)

Consequently, when presented with two sets of readings, in the vast majority of cases, data comparison was performed by either considering the “closeness” of the two average values or by comparing the individual values from each data set.

5.1.5 Probe dealing with the “true” value

Probe 14, the last question on measurement, explores students’ views on whether a “true” value can be obtained by using sophisticated instruments.

Finally, you think about how the scientists may improve their measurement.

A: With enough money and the best equipment, the scientists can design an experiment that would give them the true value of the magnetic field.

B: I do not agree! I think that the scientists will never know the true value of the magnetic field, no matter what they do.

The views of the participants about the existence of a “true” value are listed in Table 13.

Table 13: Responses of the GEPS and mainstream participants for probe 14.

Paradigm	Response type	Codes	GEPS	Mainstream
P	Technology is always being improved.	A30; B30	24 (21%)	7 (11%)
P	Only a value close to the “true” value can be obtained.	A21; B21.	10 (9%)	11 (17%)
P	The experiment will be improved leading to the “true” value.	A10; A11; A14; A20; B23.	16 (14%)	2 (3%)
P	It is impossible to know if the “true” value is obtained when some factors cannot be controlled.	B40.	13 (11%)	1 (2%)
S	All measurements or apparatus have inaccuracies.	B41; B42; B43; B44; B60; B70.	18 (16%)	18 (28%)
S	Only the best approximation or the most accurate value can be obtained.	A12; B12; B13; B23.	13 (11%)	20 (31%)
-	Not able to code response.	U00	21 (18%)	5 (8%)
Total			115 (100%)	64 (100%)

The number of students associated with the point paradigm was 63 in 115 (55%) for the GEPS group and 21 in 64 (23%) for the mainstream group. There were more mainstream (38 in 64, so 59%) than GEPS (31 in 115, so 27%) students categorised according to the set paradigm.

The view that new sophisticated apparatus will yield the “true” value, as represented by the written response below, is characterised according to the point paradigm:

Technology is always increasing and evolving within time, equipment will be designed that will be able to calculate a true value. (354)

Furthermore, the point paradigm is evident in the view that it is impossible to know the “true” value but a value close to the “true” value can be achieved. A student wrote:

The scientists can only approximate the true value, and improve the approximation so that it is as close as possible to the true value. (253)

Finally, point thinking underlies the view that it is not known if the “true” value is obtained as external conditions cannot be controlled. For example:

Even though they use the best equipment, they cannot find out the exact value of magnetic field. Because there is many things that can influence the value of magnetic field and we don't know what, and how they affects to the magnetic field. (228)

Respondents are classified according to set paradigm in cases where they believe that there are inaccuracies or uncertainties in all measurements. Even when new instruments are used, only a more accurate value can be obtained. Samples of written statements which highlight these ideas include:

The scientists can improve their measurement by using more advanced equipment. But it is impossible to eliminate all the factors that causing experimental error. (215)

True meaning that it is 100% certain that the value is that value. Equipment can only measure to a certain degree of accuracy, no matter how expensive it is. It may be more accurate than others but it cannot be 100% accurate. (225)

A large percentage (15%) of the entire sample, 18% (21 in 115) of the GEPS students and 8% (5 in 64) of the mainstream students, was non-codeable. Most of these students rephrased the text in the probe when justifying their actions or provide an irrelevant response. Examples of the students' written statements include:

Using the correct equipment / the best equipment a true value can be taken. With the best equipment and experienced scientists an experiment can be designed to get a true value. (320)

With enough money and equipment scientists can find the exact value. In my opinion if they take all the existing theories about Magnetic field and put them together with some new ideas it might work for them. (299)

In summary, respondents associated with point paradigm firmly believe in the existence of a “true” value which is attainable in principle. In contrast, students who are classified according to the set paradigm argue that the “true” value does not exist. Scientists work with an “accepted value” which could become more accurate with improved technology.

5.1.6 Overall categorisation of measurement views

A total of eight probes dealt with views on measurement. For each student, the whole set of the measurement probes were considered and the number of point and set responses were counted thus classifying the participant’s overall view on measurement according to the point or set paradigm. A participant’s overall view was associated with the point paradigm if there were a total of five or more “point” responses. The same criterion was applied for overall classification according to the set paradigm. A “mixed” category was used when there was a total of four responses which are typical of the point paradigm together with four responses associated with the set paradigm. A respondent’s overall view was non-codeable when a total of two or more responses were non-codeable.

The results obtained for the measurement probes after classification as point paradigm, set paradigm and “unclassifiable”, are tabulated in Table 14.

Table 14: Students' overall use of the point and the set paradigms.

	GEPS	Mainstream	Total
Point paradigm	104 (91%)	27 (42%)	131 (73%)
Set paradigm	4 (3%)	31 (48%)	35 (20%)
Unclassifiable			
• Mixed	5 (4%)	5 (8%)	10 (6%)
• Non-codeable	2 (2%)	1 (2%)	3 (1%)
Total	115 (100%)	64 (100%)	179 (100%)

A total of 179 students completed the questionnaire: 115 participants for the GEPS group and 64 for the mainstream cohort. From the GEPS sample, 104 respondents were classified as using the point paradigm, 4 using the set paradigm, and 7 were unclassifiable. The latter constituted of 5 mixed and 2 non-codeable students.

Out of the 64 mainstream students, 27 of them were categorised as using the point paradigm, 31 were using the set paradigm and 6 were unclassifiable. The unclassifiable group was made up of 5 mixed students and 1 non-codeable student.

5.2 Ideas about the Nature of Science

The coding of the NOS probes was performed using a similar procedure to that of the measurement probes described above.

5.2.1 Probe dealing with the nature of scientific knowledge

The views of students on the qualities that make certain type of knowledge “scientific” are explored in probe 1. The text is presented below:

You and a group of friends are discussing your views about the nature of scientific knowledge. You wonder what makes certain types of knowledge “scientific”?

Table 15 summarises the ideas expressed by the sample on the nature of scientific knowledge.

Table 15: Responses of the GEPS and mainstream students for probe 1.

Response type	Codes	GEPS	Mainstream
Scientific knowledge provides explanations about the behaviour of nature.	A12.	59 (51%)	26 (41%)
Experimental evidence is needed for knowledge to be considered scientific.	A20; A21; A22; A23.	23 (20%)	30 (47%)
Scientific knowledge is acquired from scientific disciplines which consist of laws, theories and calculations.	A60; A61; A80.	14 (12%)	- (0%)
Scientific knowledge is based on facts.	A10; A11	1 (1%)	7 (11%)
Scientific knowledge involves the use of human inference.	A41; A45.	4 (3%)	- (0%)
Scientific knowledge is reliable and leads to progress by providing solutions to problems.	A71; A72.	3 (3%)	- (0%)
Not able to code response.	U00	11 (10%)	1 (1%)
Total		115 (100%)	64 (100%)

The largest proportion of the participants believed that scientific knowledge explains or describes the complex behaviour of nature. The following responses were given:

Scientific knowledge is the understanding of our universe and our environment. This form of knowledge explains to us how living organisms function and live with one another. Scientific knowledge explains to us how nature works by applying various “laws” established through out many centuries. Science deals with the way we see the world and give explanations for bizarre phenomena. (226)

Understanding the physical world around us and how it works. (212)

Furthermore, for knowledge to be considered scientific, experiments which provide evidence is a necessity. The quotes below represent this belief:

It is knowledge derived through scientific enquiry which is a method of fitting observed data obtained by experimentation into a theory explaining those facts. Scientific knowledge is therefore based on evidence and is subject to be changed when conflicting evidence is found. (203)

It is knowledge that comes from scientific research and is proven to be true. There is experimental evidence to show that the scientific fact is true. (230)

According to some participants, scientific knowledge includes laws and theories together with mathematical calculations and formulae which characterise science. The responses which follow highlight this view:

I think scientific knowledge is a some kind of a knowledge that scientific, that means that involves a lot of application of laws, properties and rules. A person who has acquired scientific knowledge should have now know to apply laws and rules. (287)

Scientific knowledge is knowledge that has to do with discovery in which a lot of measurements and calculations are done. (310)

Two main ideas were evident for probe 1. Scientific knowledge deals with the behaviour of nature and hence provides more understanding about observations made in nature. Furthermore, experiments are the key for differentiating between scientific and non-scientific knowledge.

5.2.2 Probe dealing with the origins of laws and theories

The origins of laws and theories are investigated in probe 2. The text for probe 2 reads:

You now think about what scientists do.

A: Nature follows exact laws and scientists discover these laws.

B: No, scientists construct theories to explain what they observe in nature.

C: I have another view which I will explain.

The views displayed for the origin of laws and theories in science are shown in Table 16.

Table 16: Responses of the GEPS and mainstream students for probe 2.

Response type	Codes	GEPS	Mainstream
Nature is made up of its own laws and rules.	A10; B10; C10; A20; B20; C20; A21; B21.	50 (43%)	21 (33%)
Experiments are used to understand the behaviour of nature.	B30; C30; B31; C31; B32; C32; B34; C34.	22 (19%)	16 (25%)
Theories are simple ways of explaining what has been observed in an experiment or in nature.	B52; A80; B80; C80.	13 (11%)	15 (23%)
Scientists discover the laws of nature and also construct theories.	A90; C90.	4 (4%)	6 (10%)
Scientists help in new discoveries in science and improvements of everyday life.	A40; B40; C40.	8 (7%)	- (0%)
Scientists model nature by using logic, calculations and formulae.	B50; C50; B53; B60; B62.	4 (4%)	4 (6%)
Not able to code response.	U00	14 (12%)	2 (3%)
	Total	115 (100%)	64 (100%)

For probe 2, the predominant belief was that the laws of nature already exist and are discovered through experimentation. The following written statements describe this type of reasoning:

Nature performs itself by its own principle. Say for instance, an apple falls down a tree is derived by the gravitational force. Newton only discover it not construct it. The phenomena or relationships are originally existed in nature to be discovered. (215)

Basically laws governing nature has been there or around all the time. It is the scientists job to discover it and make use of it if needed. E.g gravity was there all along. It was just waiting quietly for Newton to discover and understand it. (285)

I believe nature follows laws, slowly mankind discovers these laws by means of experiments. These laws must apply for all situations in nature. (212)

Moreover, scientists formulate theories from observations. These hypotheses are checked through experimentation. For example:

Scientists observe the world around them and try to deduce a reason why things happen the way they do. A lot of times theories are made to explain a view, but in a few years another set of theories come in with another point of view. These theories are thus experimented with to see if they are able to reproduce and prove the theory. (204)

Scientists come up with a theory and then they try to justify their theory so that it becomes real. By doing experiments or by using equations they prove their theory which then becomes a new law. These new laws can be used to prove other theories and once again become even newer laws. (343)

Scientists observe and question phenomena that occur naturally, eg. an object falls towards the ground when it is dropped. Scientists then suggest a hypothesis or theory to explain or suggest explanation of the observation, eg. the object falls due to the force of the earth on the object. Scientists then design experiments to test the hypothesis to determine whether it is true for all cases, eg. testing the gravitational pull of objects on earth versus objects on the moon. (275)

Some students believe that theories are constructed for simpler understanding of the complex behaviour of nature. The quotes which follow characterise this kind of reasoning:

Scientists observe their surroundings and try to understand it. They develop theories about why things are the way they are. They put logic into things. They write formulae and theories to give the general understanding of a certain situation. (234)

To say that nature follows exact laws is not strictly true and therefore scientists can only construct theories to explain their observations. These theories can be extremely accurate but it is not possible for a finite human mind to fully comprehend an infinite universe and its infinitely complex laws by which it is governed. (231)

In a few cases, as in the explanations provided below, it was argued that scientists discover the laws of nature but also construct theories. These theories are simpler ways of explaining the outcomes of an experiment or the observations made from nature.

In my opinion scientists discover some laws, construct theories about what they see and try to adapt what they see to fit these laws or try to prove their theories in order to justify their views. (209)

Well, I actually agree with both A and B as I believe Nature follows principles (of which most can be proved scientifically) however scientists do not always discover these laws- they are sometimes just proved by scientists (through construction of varies justifiable theories). Scientists therefore enable others to observe (read, learn about, etc) their simplified explanations of something very complicated (or just sound complicated). (348)

To summarise the main views of the students, on one hand, the laws of nature exist out there to be discovered by scientists through experimentation. On the other hand, theories are constructed from observations which are then checked through experimentation. These theories provide a better and clearer understanding of the behaviour of nature.

5.2.3 Probe dealing with scientific experiments and theories

Probe 3 investigates whether scientific experiments or scientific theories are prioritised for the origin, creation and evolution of scientific knowledge.

You continue to think about science.

A: New scientific knowledge is based on the results from scientific experiments.

B: No, new scientific knowledge can result from existing scientific theories.

C: I have a different idea.

Table 17 provides an overview of the range of responses of the participants for probe 3.

Table 17: Responses of the GEPS and mainstream students for probe 3.

Response type	Codes	GEPS	Mainstream
Results from experiments are more reliable.	A20; C20; A22; C22; A50; B20.	23 (20%)	15 (23%)
Experiments provide more information about what is being investigated.	A23; B23; C23; B60; A62; B62; B71; C71; B72.	27 (23%)	9 (14%)
Experiments are used to prove a hypothesis.	A11; B11; C11; B13; C13.	17 (15%)	13 (20%)
Both scientific theories and the scientific experiments must be used.	C80.	20 (17%)	23 (36%)
In science highly sophisticated apparatus is used.	A34; B34; C34.	7 (6%)	1 (2%)
Experiments lead to new discoveries in science.	A42.	4 (4%)	1 (2%)
Existing scientific theories are used to design new experiments.	A73.	1 (1%)	- (0%)
Not able to code response.	U00	16 (14%)	2 (3%)
	Total	115 (100%)	64 (100%)

The largest proportion of the students prefers scientific experiments over scientific theories for the generation of new scientific knowledge. A scientific experiment is the source of reliable evidence or information. The samples of responses given below highlight this particular view:

Existing scientific theories are not guaranteed to be absolutely true. We might derive some sort of inspiration from accidental happening or existing scientific theories etc, but to verify it we need substantial proof through scientific experiment. (215)

A theory can only become scientific knowledge once it has been tested and proved with experiments. (240)

Scientific experiments are carried out for many years before it is established that the behaviour of a particular object, animal, etc is considered true and most important of all, that the conclusion reached from these various experiments is logical. (226)

However, the belief that a scientific experiment together with a theory is required for the construction of new scientific knowledge is also recognised. The existing theories provide a framework for current knowledge. These theories can be further explored to yield more and novel information. The following responses typify the category of decision described above:

Once again, I consider the truth to be a combination of A and B. On the one hand, scientific experiments could suggest new theories etc, yet most scientific experimentation is to prove/disprove theories. On the other hand, existing scientific theories often involve complicated and observe mathematics which may not have immediately obvious physical applications/implications, and so continued study and interpretation of existing theories, can and does, lead to new knowledge. (205)

Again, both A and B are viable. All scientific knowledge is from existing theories. A theory can be further exploited to gain further information, and therefore, new knowledge. Results from new scientific experiments will also add to the ever increasing amount of knowledge. (206)

From the different responses obtained for probe 3, it may be concluded that many students

believe that the construction of scientific knowledge requires the use of scientific experiments together with scientific theories. However, the scientific theories are merely “scientific claims” which must be validated by experiments as the latter are more accurate and trustworthy.

5.2.4 Probe dealing with the purpose of scientific experiments

The role and importance of scientific experiments in a scientific endeavour are explored in question 4.

You and your friends now talk about scientific experiments.

What is the purpose of a scientific experiment?

The different categories of reasoning for the purpose of scientific experiment in a scientific endeavour are as shown in Table 18.

Table 18: Responses of the GEPS and mainstream students for probe 4.

Response type	Codes	GEPS	Mainstream
Scientific experiments are used to validate a hypothesis by providing evidence which proves whether it is correct.	A20; A22.	57 (50%)	33 (51%)
Scientific experiments yield accurate and reliable outcomes.	A30; A31; A32; A50.	12 (10%)	21 (33%)
Scientific experiments provide more information about what is being investigated.	A33.	15 (13%)	5 (8%)
Scientific experiments help to better understand scientific theories.	A11.	12 (10%)	3 (5%)
Scientific experiments lead to progress in science and in daily life.	A40; A41.	13 (11%)	2 (3%)
Scientific experiments help to memorise scientific knowledge.	A60.	3 (3%)	- (0%)
Not able to code response.	U00	3 (3%)	- (0%)
	Total	115 (100%)	64 (100%)

Just over half of the students believe that a scientific experiment is used to prove a hypothesis. Experiments are more reliable than scientific theories and provide more information about what is being investigated. The explanations which follow were given:

The purpose of scientific experiment is to prove theories in order to gain knowledge and understanding. Experiments allow us to test the accuracy of our understanding in order to broaden our knowledge of the unknown. (208)

Someone will have an idea or theory about something scientific, the natural idea would be to put this theory into practice, and see whether it is accurate or not, scientists do this in the form of experiments, repetition of experiments is the way to make sure the theory is correct. (212)

An experiment's purpose is to test or validate theories. It is not good enough to just come up with a new theory without being able to prove the truth in your theory or without being able to show that your theory can be put to practice and that it is useful. Experiments are the way in which we give this proof and demonstrate the usefulness of our scientific theories. (214)

In many cases, it is argued that scientific experiments lead to new discoveries or improvements in the field of science or in everyday life:

The main purpose of having scientific experiment is that to discover the certain constant laws of nature's phenomena, so that we can predict future. (228)

I think that the main purpose is to improve or make things more easier in this modern world. The most of experiments are done in order to try something new and improve what we have done at the moment. In some experiments we just want to determine whether something is true or not. (291)

The views emerging from probe 3 and 4, on the role of scientific experiments in a scientific enterprise, agree with one another. Scientific experiments are required to provide evidence about the system under investigation. Experimental results are more accurate than theoretical ones, resulting in information which is reliable and which can be used for progress either in science or in everyday life.

5.2.5 Probe dealing with scientific method and creativity in experiment

Probe 7 explores the relative roles of the scientific method and creativity when conducting an experiment.

You observe that the scientists are discussing what they should do in their experiments.

A: I think that scientists always strictly follow the “Scientific Method” which prescribes a sequence for carrying out an experiment.

B: No, I think that scientists also use their creativity when carrying out an experiment.

Table 19 presents the different explanations the two cohorts used when completing probe 7.

Table 19: Responses of the GEPS and mainstream students for probe 7.

Response type	Codes	GEPS	Mainstream
Creativity is used for more discoveries in science.	B56; A90; B90.	31 (27%)	19 (30%)
Creativity is used for improvements of the experimental results.	B91.	11 (10%)	12 (19%)
Scientists design their own procedures depending on the type of the experiment.	B60.	3 (2%)	9 (14%)
The scientific method is the most accurate method that should be used to have a successful experiment.	A20; B20; A11; A21; A40; A41; B41; A42; B42.	45 (39%)	17 (27%)
Both the scientific method and creativity are used for part of the experiment.	B50; B51; B55; B80.	6 (5%)	4 (6%)
Only creativity is used as the scientific method can be faulty.	B52; B54; B94.	8 (7%)	1 (1%)
Not able to code response.	U00	11 (10%)	2 (3%)
Total		115 (100%)	64 (100%)

The use of scientists' creativity during an experiment was the most frequent choice of the respondents. Creativity is used to improve on experimental results and increase the explanatory power of current scientific knowledge. The responses which follow were obtained from the sample:

If scientists followed a 'set of rules' they would limit themselves to what they know. Creativity allows them to expand ideas and revolutionize scientific concepts. Without creativity, scientists would be confined to what they know and simply dwell on that. As a matter of fact, science would not develop broadly without creativity. (226)

If scientists did not use creativity when carrying out experiments then no new discoveries would be made. Some of the greatest discoveries ever were made through the creative manipulation of experiments. (227)

Some students believe that the scientific method together with the creativity of scientists is used during the experiment. Different explanations, as portrayed by the explanations below, were given about where both creativity and scientific method is used while conducting the experiment.

Scientists use their creativity before carrying out an experiment more than during an experiment. I think they should know exactly what they are to do before an experiment by accurate and detailed calculations and so on. They should follow the prescribed steps unless there is suddenly a mistake or accident happening. (215)

Scientists do use their creativity in determining what type of experiment to do, but when carrying out the experiment they still do it scientifically. (240)

Yes, scientists do follow the scientific method, but this involves creativity to design an experiment, and also to construct + adapt theories once results have been obtained. (273)

Another view was that there are no prescribed steps to be followed for conducting an experiment. Scientists can design their own procedures depending on the type of experiment. The responses below illustrate this belief:

Different scientific problems require different solutions- there is no all-encompassing method that can describe uniquely the steps that need to be followed to carry out every experiment. (250)

In some situations the prescribed procedure is not an efficient way of going about an experiment (e.g gathering indirect evidence of black holes) and the scientists need to get creative with experimental procedures. (203)

However, many students prefer to use scientific method only, during an experiment. According to them, the prescribed steps of the scientific method must be followed as they are accurate and hence ensure the success of an experiment by yielding consistent and reliable experimental results. The samples of responses which follow describe these categories of reasoning:

To be creative while performing an experiment, and deviate from the agreed-upon method, would jeopardise the accuracy and correctness of the results. It would also make published results less likely to be accepted by the scientific community. (229)

For most accurate results it is important to follow proper scientific methods. (260)

The 'Scientific Method' is certainly one of the best methods developed to carry out a clear, accurate experiment and come to a logical conclusion. (276)

In a few cases, it was argued that the scientific method must be used, as in principle science is made up of laws and procedures which need to be followed. The two written statements below justify this belief:

By following the "Scientific Method" the experiment will be genuine because there are some laws of nature involved in there and have to be considered when carrying out an experiment. (286)

Science is all about methods, equations and steps to follow. Perhaps there are some cases where creativity is used, but I agree more with A. Science is about raw knowledge of the subject at hand and steps need to be followed. (347)

Two main views were predominant from the different responses received for probe 7. On one hand, creativity is important during an experiment in order to obtain better experimental results and to broaden the framework of scientific knowledge. On the other hand, only scientific method has to be used to ensure that accurate, trustworthy and infallible results are obtained.

5.2.6 Probe dealing with mismatch between theoretical and experimental results

The last NOS probe, probe 13, deals with the action and decision of students when experimental and theoretical results contradict each other.

After analysing their data, the scientists find that their measurement of the Earth's magnetic field does not agree with the value predicted by their theory. You discuss what the scientists should do.

A: I think that the scientists might now have to revise their theory.

B: No, the scientists should reject the value obtained from their experiment.

C: I have another idea about what they should do.

The various explanations received from the sample are summarised as shown in Table 20.

For probe 13, preference is given to experimental results over theoretical ones. According to most of the students, a theory must be revised as it is based on assumptions and hence may be inaccurate. For example:

Since the results didn't correspond with their theory, the problem lies with their theory. The results will always be the same but the theory can change. (235)

Theory is just an assumption, so that it never be perfect, so there is a need to revise their theory by means of using the result they got from measurement. (228)

Table 20: Main decisions of the GEPS and mainstream students for probe 13.

Response type	Codes	GEPS	Mainstream
Experimental results are more accurate and reliable than theoretical results which may be inaccurate.	A10; C10; A12; C12; A13; A20; A21; A30; C30; A31.	56 (49%)	29 (45%)
Both theories and experiments must be checked.	A90; C90	15 (13%)	12 (19%)
The theory must be changed if after repeating the experiment the experimental and theoretical results still contradict each other.	A41; B41; C41; A92.	10 (9%)	9 (14%)
The experiment must be repeated.	A40; C40; A42; A44; C44.	9 (8%)	6 (9%)
Experiments always involve errors.	C43; C61; A60; C80; B61; C60.	5 (4%)	4 (7%)
A theory can never be changed. It has been proved by previous experiments.	B50; C50.	3 (3%)	2 (3%)
Experimental and theoretical results must be the same.	C81.	4 (3%)	- (0%)
Not able to code response.	U00	13 (11%)	2 (3%)
Total		115 (100%)	64 (100%)

Few students emphasise the need to repeat the experiment followed by a change in the theory if the experimental and theoretical values still do not agree with each other. The following two responses are representative:

They should check all their results, redo the experiment (and have others do it) and if it still doesn't fit with the theory they should revise the theory. (225)

The scientists must now go and revise their theory. The point of the experiment is to validate the theory. If the results of the experiments contrast with the theory, it is the theory which must be revised, as the results are scientifically conclusive. (216)

Some students believe that both the theory and the experiment need to be checked as the origin of the mistake cannot be ascertained. The responses below described this idea:

Both the experiment's results and the theory should be checked as we do not know which is producing the error. (202)

Revise their experiments, redo it, check for mistakes, miscalculations or other factors that could have changed their results. They can also take another look at the theory if the experiment seems sound. (243)

Only in a few instances it was stated that experiments may involve inaccuracies and approximations and hence priority is given to the theoretical results. This category of reasoning is exemplified by the following explanations:

Theory is more accurate than readings because readings can be influenced by external sources. (264)

If they followed very well the theory for sure that the answer does not differ that much. So, it is because of weather conditions or another factor probably as I said before. (359)

From the various responses obtained, it is clear that preference is given to experimental results over theoretical ones. Theoretical values are considered as rough estimates. Experimental results are more accurate and reliable with the result that theories must be changed in order to be consistent with the experimental outcomes.

In this chapter, the emphasis was mainly on the analysis of the responses for the individual probes in the VASM questionnaire. The method used to code the students' responses, the grouping of the various codes to represent the students' main beliefs for the different probes and the categorisation of the measurement responses according to the point and set paradigm, were outlined.

6. Results

6.1 Students' views on the nature of scientific measurement

A summary of the results obtained for the students' views on the nature of scientific measurement, for the GEPS and the mainstream cohorts, and as an ensemble, are depicted in Figure 8. For the present study, few students (6% of the entire sample) were categorised with mixed reasoning. This percentage was considered negligible and insufficient to perform a separate reliable analysis. Only 1% of the responses in the study were non-codeable. Hence, the mixed and the non-codeable views were grouped together as "unclassifiable". As seen in Figure 8, the majority of the students (73%) were classified according to the point paradigm compared to only 20% whose beliefs were consistent with the set paradigm. However, when the mainstream and the GEPS groups were analysed separately, a considerable difference was observed in the proportion of students associated with the point and set paradigms. Most of the GEPS participants (91%) were categorised according to the point paradigm while only 3% were associated with the set paradigm. In contrast, for the mainstream cohort, 42% were classified according to the point paradigm and 48% according to the set paradigm. Moreover, a 2×2 chi-squared test performed on the data in Table 14 (from chapter 5), excluding the unclassifiables, yielded a value of 56.1 with $p < 0.001$ for 1 degree of freedom thus indicating that there is a significant difference between the GEPS and mainstream students' views on measurement.

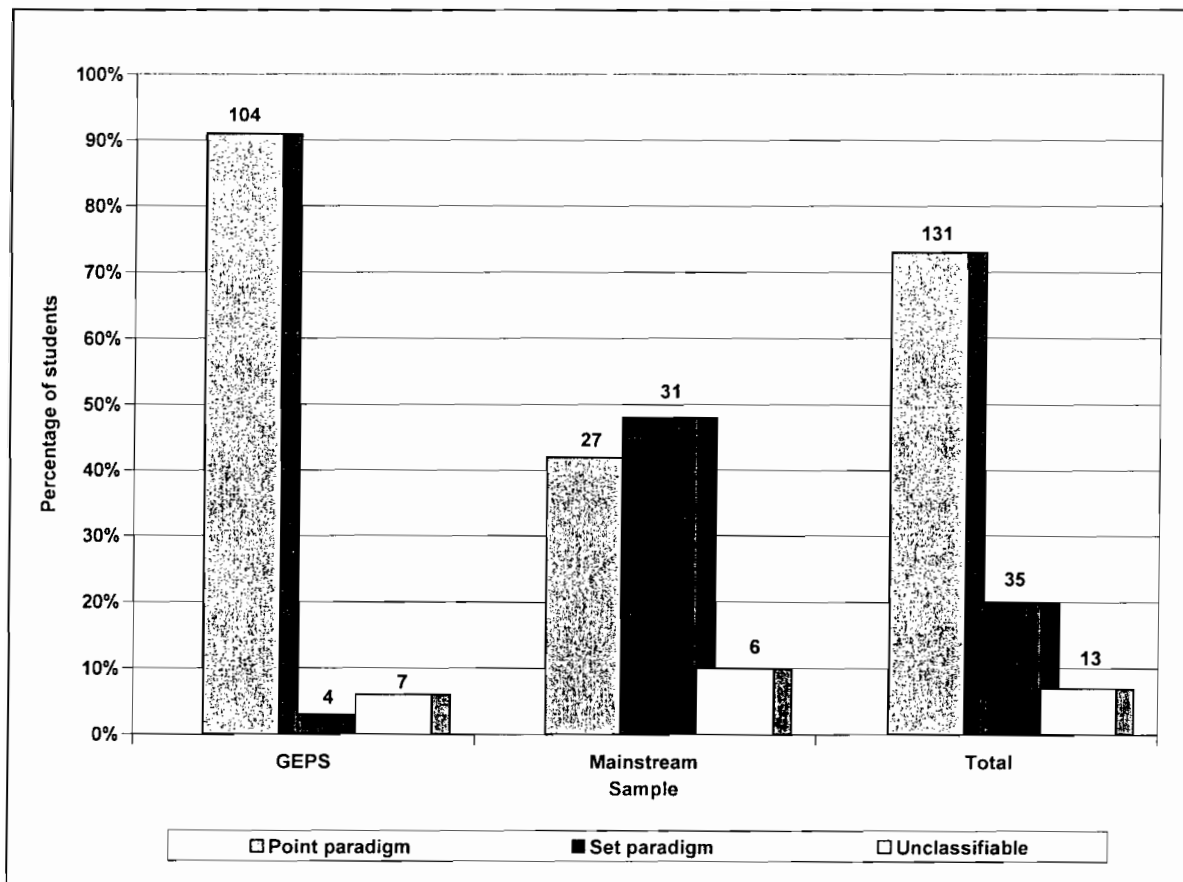


Figure 8. Students' use of the point and set paradigm across measurement situations. (Also shown are the absolute numbers for each category).

The small percentage of unclassifiable responses (7%) suggests that the majority of the participants in the study found most of the measurement probes to be understandable. However, there was a considerable difference in the responses to probe 9 for the two groups of students. Most of the GEPS students misinterpreted this probe as asking about the environmental conditions necessary to carry out an experiment. The temperature of the room was interpreted to be equivalent to the room temperature. The value 25 °C, which according to them is the room temperature, was compared to the value they read off from the analogue scale. For example:

The value read off from the scale is 25 °C (280)

The quote which follows illustrates the written explanation provided:

The chemicals and the other laboratory substances need to be kept at room temperature, should the temperature exceed that a disaster would. (280)

Since it is clear that the actions and decisions of the students are associated with the point paradigm, a code was allocated to fit this category of reasoning for the GEPS sample. For the mainstream group, probe 9 was generally understood as intended. Examples of responses obtained include:

The value read off from the scale is $24^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$. (203)

The dial on the thermometer can only be read accurately to a degree celsius, therefore my answer can only be given to that. The answer can lie anywhere between 23.5°C and 24.5°C . (203)

The value read off from scale is 24°C or 297 Kelvin. (204)

The thermometer displays that the temperature is on the 24°C mark. (204)

These distinctions in the responses to probe 9 may be explained by the differences in language mastery of the two groups of students, in this case, the interpretation of the task. The students were asked to read a given analogue scale and explain their answer. However, several GEPS students seem to have attempted to explain the value of the reading they found, whereas the mainstream students explained the way they established their reading.

6.2 Students' views on the nature of science

6.2.1 Nature of science profiles for the VASM questionnaire

The present work aims to investigate whether there is a relationship between students' views on the NOS and on the nature of scientific measurement. To facilitate the analysis of

the NOS responses, profiles were designed to represent the different aspects of the NOS probed in the VASM questionnaire. The term profile may be understood as a set of relevant descriptors which are assembled to represent the overall view of a student. This allows for each student's belief to be considered holistically as they represent the overall NOS views of each student across all the probes and, in turn present frames which facilitate the interpretation and identification of the students' NOS conceptions (Moss *et al.*, 2001).

For the present study, the design of the profiles for the NOS probes was completed in two stages. A code was first assigned to the different responses of the NOS probes as outlined in chapter 4. A group of 10 participants, 5 from the GEPS cohort and 5 from the mainstream cohort, was then randomly selected. For each student, the set of six NOS probes was considered together. The responses provided for each of the six NOS probes were summarised and grouped together. The allocated codes were used as a guide and confirmation to ensure that the students' overall NOS views were depicted as intended. The process revealed that most of the students' responses could be captured in four profiles, which are shown in Table 21.

Profile 1 is characterised by the view that scientific knowledge is acquired from observations followed by the construction of theories. The theories are simple ways of explaining the complex behaviour of nature. In order to be accepted as scientific knowledge, they have to be tested by experiments which provide reliable and accurate evidence. Creativity plays a crucial role during an experiment, without which the experiment will not be successful and no new discoveries will be made in science. However, when there are discrepancies between theoretical and experimental results, either the theory or the experiment may be inaccurate as the origin of the difference cannot be ascertained.

Table 21: Student profiles based on responses to the NOS probes.

Profile 1	Profile 2	Profile 3	Profile 4
Scientific knowledge explains or describes the behaviour of nature and is based on experiments and evidence.	Scientific knowledge explains or describes the behaviour of nature and is based on experiments and evidence.	Scientific knowledge explains or describes the behaviour of nature and is based on experiments and evidence.	Scientific knowledge explains or describes the behaviour of nature.
Scientific theories are constructed from observations for simpler and better understanding of the complex behaviour of nature.	Nature has its own laws which are discovered through experimentation.	Scientific theories are constructed from observations for simpler and better understanding of the complex behaviour of nature.	Nature has its own laws which are discovered through experimentation.
Theories are tested, validated and revised through experimentation.	Theories are tested, validated and revised through experimentation.	Theories are tested, validated and revised through experimentation.	Theories are tested, validated and revised through experimentation.
Scientists may use their creativity when undertaking experiments for new discoveries, improvements and to be successful.	Scientists may use their creativity when undertaking experiments for new discoveries, improvements and to be successful.	Scientists strictly use the scientific method when undertaking experiments as they must be successful and have accurate results.	Scientists strictly use the scientific method when undertaking experiments as they must be successful and have accurate results.
If experimental results and theories disagree, then both theories and experiments may be inaccurate.	If experimental results and theories disagree, the experimental results are more accurate.	If experimental results and theories disagree, the experimental results are more accurate.	If experimental results and theories disagree, then both theories and experiments may be inaccurate.

Profile 2 is characterised by the view that the laws of nature are not constructed by scientists. Nature follows its own patterns which are discovered through experimentation followed by the formulation of theories for better understanding of the complex behaviour of nature. Experiments are necessary for distinguishing between a scientific and a non-scientific knowledge whereby the former deals mainly with the behaviour of nature. The use of creativity in an experiment is important for new discoveries in science and for improvements in the experimental strategies. When experimental and theoretical results are

not consistent with each other, the theory has to be revised as it is based on experiments which provide more accurate and trustworthy evidence.

Profile 3 includes the belief that scientific knowledge is generated from observations of nature followed by the construction of scientific theories which are then tested through experimentation. The scientific method must be followed when conducting an experiment as it is accurate and therefore yields results which are consistent with one another. An experiment is necessary for the acquisition of reliable scientific knowledge and has priority over a scientific theory. Hence, when experimental and theoretical results do not agree, the theory has to be revised as it is considered to be only a scientific claim and is therefore dependent on confirmation by experimental results.

Profile 4 is described by the view that scientific knowledge provides explanations for the behaviour of nature. Nature has its own laws which are discovered through experimentation. Theories are then constructed to provide better understanding about the observations made. The scientific method has to be used during an experiment as scientists need to be successful and have reliable results. When experimental and theoretical results are inconsistent, then both the theory and the experiment must be checked as either may be inaccurate.

6.2.2 Allocation of the NOS profiles

Each student, from both cohorts, was assigned to one of the four profiles. The allocation of profiles was performed by considering the main ideas displayed across the six NOS responses and comparing them with the profile which best represents the student's overall NOS views. A participant's profile was categorised as unclassifiable when there were two or more responses which could not be matched to a profile. The percentage of students, in the entire sample, with an unclassifiable profile was 14%, that is 19 in 115 from the GEPS group and 6 in 64 from the mainstream cohort, respectively. Table 22 shows the distribution of assigned profiles for the two groups.

Table 22: Student frequencies for the different profiles. (n=179)

		GEPS students (n=115)	Mainstream students (n=64)	Total (n=179)
NOS profiles	Profile 1	43 (37%)	35 (55%)	78 (44%)
	Profile 2	25 (22%)	9 (14%)	34 (19%)
	Profile 3	21 (18%)	8 (13%)	29 (16%)
	Profile 4	7 (6%)	6 (9%)	13 (7%)
	Unclassifiable	19 (17%)	6 (9%)	25 (14%)
Total		115 (100%)	64 (100%)	179 (100%)

The majority of the students in the entire sample (44%) expressed NOS beliefs which were consistent with profile 1. When the two groups were analysed separately, profile 1 was the common NOS views displayed by 37% of the GEPS (43 in 115) and 55% of the mainstream students (35 in 64). Profile 2 described the NOS views of 19% of the students in the study. The percentage of GEPS and mainstream participants whose NOS views agree with profile 2 was 22% (25 in 115) and 14% (9 in 64) respectively. Only 16% of the students, 21 in 115 for the GEPS group, and 8 in 64 for the mainstream group exhibited the NOS beliefs which were closely represented by profile 3. Profile 4, the least common profile used, described the NOS views of 7% of the respondents in the study, 6% (7 in 115) for the GEPS cohort and 9% (6 in 64) for the mainstream group.

6.2.3 Relationship between views of the NOS and views of the nature of scientific measurement

The participants' views on measurement which were classified according to the point and set paradigms were related with their views on the NOS as represented by one of the four

NOS profiles. Table 23 and Figure 9 present the relationship between the NOS profiles and the views on measurement categorised according to the point and set paradigms.

Table 23: Relationship between the views on measurement and the NOS profiles. ($n=179$)

		Measurement paradigms			Total ($n=179$)
		Point paradigm ($n=131$)	Set paradigm ($n=35$)	Unclassifiable ($n=13$)	
NOS profiles	Profile 1	51 (39%)	19 (54%)	8 (62%)	78 (44%)
	Profile 2	30 (23%)	3 (9%)	1 (8%)	34 (19%)
	Profile 3	21 (16%)	6 (17%)	2 (15%)	29 (16%)
	Profile 4	10 (8%)	3 (9%)	0 (0%)	13 (7%)
	Unclassifiable	19 (14%)	4 (11%)	2 (15%)	25 (14%)
Total		131 (100%)	35 (100%)	13 (100%)	179 (100%)

As can be seen from Table 23 and Figure 9, profile 1 described the NOS views of 54% (19 in 35) of students associated with the set paradigm while only 39% (51 in 131) of students categorised according to the point paradigm displayed a similar profile. In contrast, 23% (30 in 131) of students classified according to the point paradigm compared to only 9% (3 in 35) of students with set paradigm reasoning have the NOS views which are consistent with profile 2. Profile 3 was adopted by roughly an equal percentage of students whose views on measurement are consistent with the point paradigm, 16% (21 in 131), and the set paradigm, 17% (6 in 35). Profile 4 described the NOS views of only 8% and 9% of students whose views on measurement are categorised according to the point and the set paradigm, respectively.

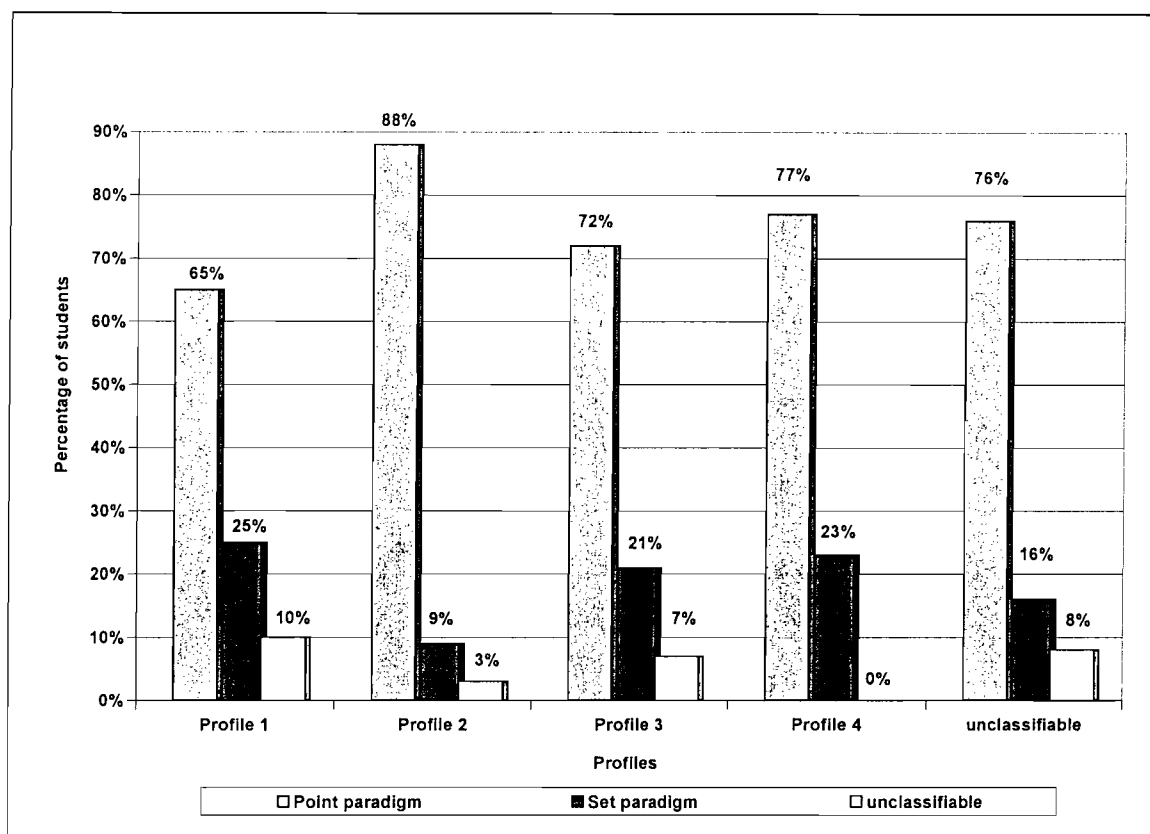


Figure 9. Distribution of students according to NOS profiles after categorisation into either the point or set paradigms.

The ratio of point paradigm to set paradigm students associated with the four profiles was calculated. Table 24 presents the proportion of students with point and set reasoning for the four NOS profiles.

Table 24: Ratio of point and set paradigm students for each profile.

	Ratio of students using point / set paradigm
Profile 1	2.7
Profile 2	10.0
Profile 3	3.5
Profile 4	3.3
Overall	3.7

It was found that a higher proportion of students with point reasoning, a ratio of 10.0, were associated with profile 2. Since the overall ratio for users of the point to set paradigms is 3.7, the much lower ratio of 2.7 for profile 1 indicates that students using the set paradigm are over-represented for this profile. Moreover, it seems that there is no significant difference in the proportion of students categorised according to the point and set paradigms being associated with profile 3 and 4 with ratios of 3.5 and 3.3 respectively, as these are both close to the overall ratio.

Consequently, from the analysis performed, it was found that a greater proportion of students categorised according to the point paradigm have the NOS views which are consistent with profile 2, while most students whose views on measurement are classified according to the set paradigm have the NOS views which are described by profile 1.

A 4×2 chi-squared analysis was also performed on the data in Table 23, excluding the unclassifiables. A value of 4.33 with $p < 1$ for 3 degrees of freedom was obtained. For significance at the 0.05 level, the chi-square value should be greater than 7.82. The value 4.33 indicates that there is no significant relationship between the views of the NOS and the views on the nature of scientific measurement.

6.2.4 Relationship between views of selected aspects of the NOS and the views of scientific measurement

The four profiles discussed above provide a combined description of the students' overall NOS views. However, this analysis does not provide clear patterns relating the holistic profiles used by students to their use of the point and set paradigms. A further analysis was therefore carried out in order to identify any trends in reasoning for a selection of key aspects of the NOS as documented in the NOS probes namely probes 2, 7 and 13. Probes 2 and 7 focus on the objectivity or subjectivity of scientific knowledge, implying, whether scientific knowledge is theory-laden and constructed and invented by scientists, or independent of any form of human intervention. The views of students on the role of scientific method for yielding the "exact value", or infallible knowledge, are also investigated in probe 7. Probe 13 was chosen as it focuses mainly on the actions and

decisions of the students when considering the relationship between experimental and theoretical results, that is, the perceived relative power of experimental results and theories. Probe 1 was seen as less important as it asked for a generalised view about the nature of scientific knowledge. Probe 3 which deals with the relationship between a scientific theory and a scientific experiment is related to probe 13 and lastly, the views expressed in probe 4 are used to confirm the student's reasoning for probe 13. The relationship between students' views on scientific measurement described by the two paradigms, and their views expressed in NOS probes 2, 7 and 13 are presented in Tables 25, 26 and 27 respectively. A chi-squared analysis was performed, excluding the unclassifiables, to determine if there is any significant link between the NOS views expressed for each of the three probes and views of measurement consistent with the point paradigm and set paradigm.

(a) Views on the origin of scientific laws and theories (from probe 2)

The main views on the origins of laws and theories provided by students categorised according to the point and set paradigms are represented in Table 25.

Table 25: Relationship between students' views of the origin of scientific laws and theories, and their views on measurement. (n=179)

		Views about measurement			Total
		Point paradigm	Set paradigm	Unclassifiable	
Views on the origin of laws and theories	Nature has its own laws.	64 (49%)	7 (20%)	3 (23%)	74 (41%)
	Scientists construct theories from observations.	57 (43%)	26 (74%)	8 (62%)	91 (51%)
	Unclassifiable.	10 (8%)	2 (6%)	2 (15%)	14 (8%)
Total		131 (100%)	35 (100%)	13 (100%)	179 (100%)

A value of 10.47 with $p < 0.01$ for 1 degree of freedom was obtained when a 2×2 chi-squared test was performed. The value, 10.47, indicates that a significant link exists between the NOS beliefs for probe 2 and being classified according to either the point or set paradigm.

From the 131 students associated with the point paradigm, 49% (64 in 131) were of the opinion that nature has its own fixed laws which are discovered through experimentation while 43% (57 in 131) believed that scientists construct theories based on observations. Around 74% (26 in 35) of students classified according to the set paradigm focus on the notion that theories are inventions of the scientist and only 20% (7 in 35) of the students with set reasoning believed that the laws of nature already exist.

(b) Views on appropriate experimental strategies (from probe 7)

The two main categories of reasoning for determining what strategies are appropriate for using experimental work to establish scientific knowledge emerge from probe 7 and displayed by students whose views on measurement are consistent with the point paradigm and the set paradigm are shown in Table 26.

Table 26: Relationship between students' views of appropriate experimental strategies and their views on measurement. ($n=179$)

		Views about measurement			Total
		Point paradigm	Set paradigm	Unclassifiable	
Views on appropriate experimental strategies	Use of scientific method only.	39 (30%)	11 (31%)	2 (15%)	52 (29%)
	Use of creativity and the scientific method.	82 (62%)	24 (69%)	10 (77%)	116 (65%)
	Unclassifiable.	10 (8%)	0 (0%)	1 (8%)	11 (6%)
Total		131 (100%)	35 (100%)	13 (100%)	179 (100%)

A 2×2 chi-squared analysis was also carried out on the frequencies presented in Table 26. The χ^2 value obtained was 0.008 with $p < 1$ for 1 degree of freedom, thus indicating that there is no significant link between the NOS views on the role of scientific method or creativity and the use of either the point paradigm or set paradigm.

Most of the students, irrespective of their classification according to the paradigmatic model, favour the inclusion of creativity when performing an experiment. A negligible difference was noted in the percentage of students associated with the point and set paradigms, 30% (39 in 131) and 31% (11 in 35), respectively, who emphasised the use of solely the scientific method during an experiment.

(c) Views on the relative power of experimental results and theories (from probe 13)

Table 27 presents the main beliefs, provided by students with point and set reasoning, on the relative power of experimental results and scientific theories, especially what to do when these conflict.

Table 27: Relationship between students' views of the power of experimental results and theories, and their views on measurement. (n=179)

		Views about measurement			Total
		Point paradigm	Set paradigm	Unclassifiable	
Views on the power of experimental results and theories	Experiments are more accurate.	96 (73%)	25 (71%)	9 (69%)	130 (72%)
	Both the theory and the experiment may be inaccurate.	20 (16%)	8 (23%)	2 (15%)	30 (17%)
	The theory is accurate.	4 (3%)	2 (6%)	1 (8%)	7 (4%)
	Unclassifiable.	11 (8%)	0 (0%)	1 (8%)	12 (7%)
Total		131 (100%)	35 (100%)	13 (100%)	179 (100%)

A chi-square value of 1.23 was obtained on performing a 3×2 chi-squared analysis on the frequencies presented in Table 27. The χ^2 value 1.23 with $p < 1$ for 2 degrees of freedom shows that there is no significant relationship between the views of the relative power of experimental results and theories and the use of either the point or set paradigm.

Most of the students associated with the point paradigm (73%, or 96 in 131) and with the set paradigm (71%, or 25 in 35) mentioned that experiments are more accurate and reliable, and consequently favour the revision of a theory when there are discrepancies between experimental and theoretical results. The belief that both the experiment and the theory may be inaccurate was expressed by 16% (20 in 131) of students who use point reasoning and 23% (8 in 35) of students associated with the set paradigm. Preference given to a scientific theory over a scientific experiment by students with either type of paradigm was negligible.

(d) Views on aspects of the NOS for different student cohorts

The mainstream and GEPS cohorts were also analysed separately. Table 28 presents the relationship between the GEPS students' views on scientific measurement described by the point and the set paradigm, and their views expressed in the NOS probes 2, 7 and 13 presented above.

The majority of the GEPS students possessed a measurement view which was consistent with the point paradigm, 104 in 115, while only 4 in 115 were associated with the set paradigm. Consequently, it was impossible to make substantial comparison on the GEPS group for their views on the NOS and the nature of scientific measurement.

Table 28: Relationship between the overall measurement views (point and set paradigms) and the NOS views expressed in probes 2, 7 and 13 by the GEPS cohort. (n=115)

Probe Number		Views about measurement			Total (n=115)
		Point paradigm (n=104)	Set paradigm (n=4)	Unclassifiable (n=7)	
2	○ Nature has its own laws.	49 (47%)	3 (75%)	3 (43%)	55 (48%)
	○ Scientists construct theories from observations.	45 (43%)	0 (0%)	3 (43%)	48 (42%)
	○ Unclassifiable.	10 (10%)	1 (25%)	1 (14%)	12 (10%)
7	○ Use of the scientific method only.	31 (30%)	3 (75%)	2 (29%)	36 (31%)
	○ Use of creativity and the scientific method.	64 (62%)	1 (25%)	5 (71%)	70 (61%)
	○ Unclassifiable.	9 (8%)	0 (0%)	0 (0%)	9 (8%)
13	○ Experiments are more accurate.	75 (72%)	2 (50%)	6 (85%)	83 (72%)
	○ Both the experiment and the theory may be inaccurate.	15 (14%)	1 (25%)	0 (0%)	16 (14%)
	○ Theory is more accurate.	4 (4%)	1 (25%)	0 (0%)	5 (4%)
	○ Unclassifiable.	10 (10%)	0 (0%)	1 (15%)	11 (10%)

In contrast, there were a larger proportion of students from the mainstream group who were classified according to the set paradigm (31 in 64). The relationship between the mainstream students' views on scientific measurement categorised according to the point and set paradigms, and their views expressed in NOS probes 2, 7 and 13 are presented in Table 29.

Table 29: Relationship between the overall measurement views (point and set paradigms) and the NOS views expressed in probes 2, 7 and 13 by the mainstream cohort. (n=64)

Probe Number		Views about measurement			Total (n=64)
		Point paradigm (n=27)	Set paradigm (n=31)	Unclassifiable (n=6)	
2	○ Nature has its own laws.	15 (56%)	4 (13%)	0 (0%)	19 (30%)
	○ Scientists construct theories from observations.	12 (44%)	26 (84%)	5 (83%)	43 (68%)
	○ Unclassifiable.	0 (0%)	1 (3%)	1 (17%)	2 (2%)
7	○ Use of the scientific method only.	8 (30%)	8 (26%)	0 (0%)	16 (26%)
	○ Use of creativity and the scientific method.	18 (67%)	23 (74%)	5 (83%)	46 (72%)
	○ Unclassifiable.	1 (3%)	0 (0%)	1 (17%)	2 (2%)
13	○ Experiments are more accurate.	21 (78%)	23 (74%)	3 (50%)	47 (73%)
	○ Both the experiment and the theory may be inaccurate.	5 (19%)	7 (23%)	2 (33%)	14 (21%)
	○ Theory is more accurate.	0 (0%)	1 (3%)	1 (17%)	2 (4%)
	○ Unclassifiable.	1 (3%)	0 (0%)	0 (0%)	1 (2%)

For probe 2, more than half of the mainstream students using the point paradigm (56% or 15 in 27) believed that nature has its own laws while only 13% (4 in 31) of the students associated with the set paradigm expressed a similar belief. However, the notion that scientists construct theories from observations was prevalent among students whose views on measurement were consistent with the set paradigm (84%, that is 26 in 31), compared to 44% (12 in 27) for participants with the point paradigm reasoning. For probe 7, a 4%

difference was noted in the percentage of students classified according to the point paradigm (30%, 8 in 27) and the set paradigm (26%, 8 in 31) who prefer the use of the scientific method during an experiment. The majority of the students associated with the point paradigm (67%, 18 in 27) and the set paradigm (74%, 23 in 31) favour the inclusion of creativity when conducting an experiment. When there are discrepancies between experimental and theoretical results as dealt within probe 13, 78% (21 in 27) of the mainstream students associated with the point paradigm and 74% (23 in 31) with the set paradigm stated that the theory must be changed. The belief that both, the experiment and the theory may be inaccurate was expressed by 19% (5 in 27) and 23% (7 in 31) of the students with point and set paradigm reasoning, respectively.

6.2.5 Trends in the NOS views for students using the point and set paradigms

The findings from the mainstream cohort support the conclusions reached when analysing the whole sample. A distinguishable trend was noted in the NOS beliefs of the mainstream students associated with the point and set paradigms for their views on the origin of laws and theories. However, no distinct patterns were observed for the views on the appropriate experimental strategies (especially the role of creativity) and the relative power of experimental results and scientific theories of students whose views on measurement are consistent with the point and set paradigms.

Figure 10 illustrates the generalised NOS views of participants categorised according to the paradigmatic framework.

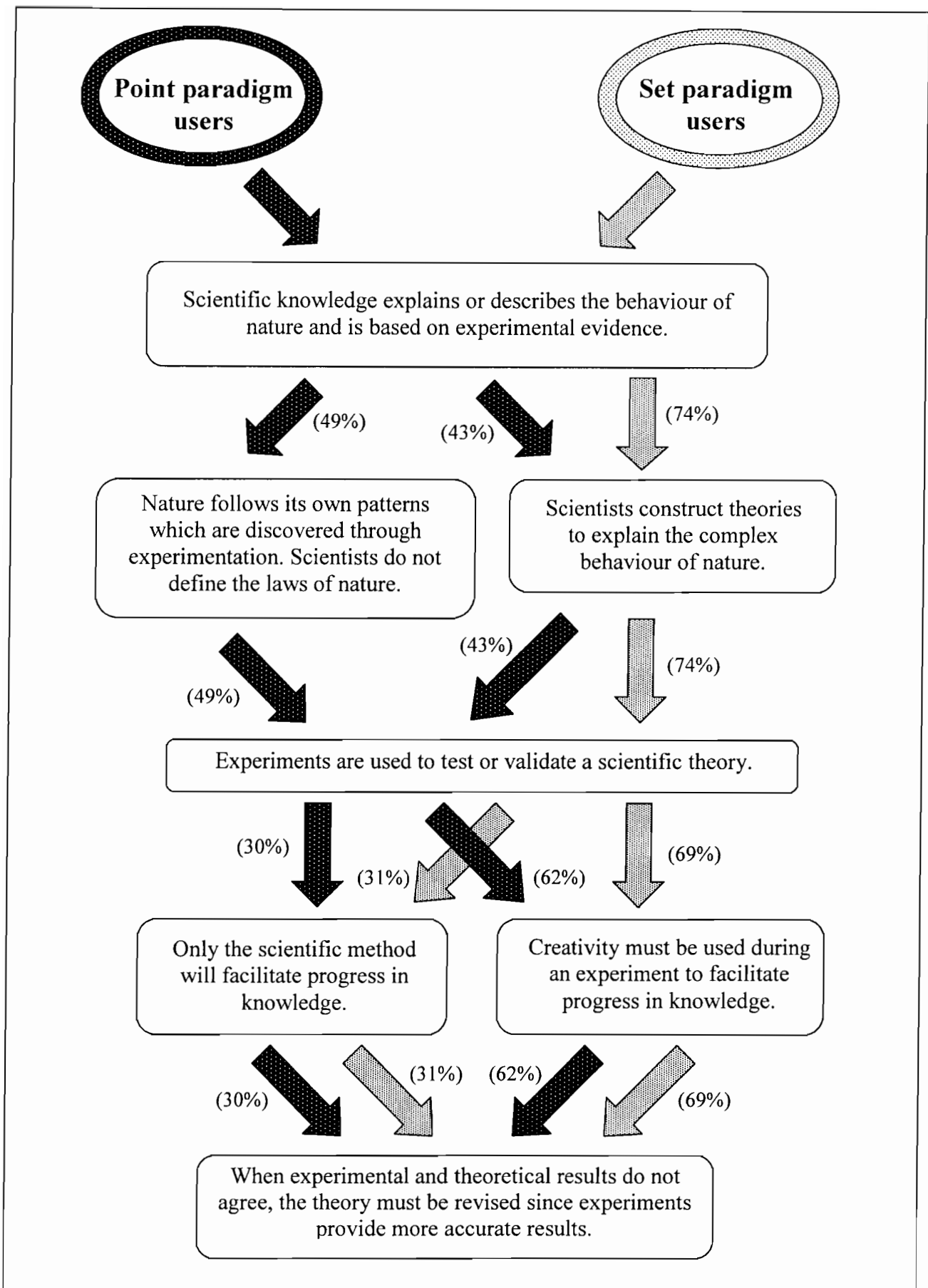


Figure 10. Generalised NOS views for students with the point and set paradigm views of the nature of scientific measurement.

Students categorised according to the point paradigm utilise two main routes for their views on the NOS. According to them, scientific knowledge provides explanations for the behaviour of nature. A scientific knowledge is either acquired by discovering the existing laws of nature through experimentation or is constructed from observations followed by the formulation of theories. Much emphasis is placed on the importance of experiments and experimental results for the generation of new scientific knowledge. Usually, a theory needs to be validated by experiments as the latter provide reliable and accurate evidence. Hence, a theory is dependent on experimental results and must be revised when experimental and theoretical results do not agree. During an experiment, the use of creativity is important as it improves the experimental results and leads to new discoveries in science.

In contrast, students classified according to the set paradigm seem to follow only one trajectory for their views on the NOS. They are of opinion that for knowledge to be considered scientific, it has to deal with the behaviour of nature. Moreover, experiments and experimental evidence are necessary requirements in a scientific endeavour. A scientific knowledge is generally constructed. Theories are generated from observations of nature and provide simple explanations for the complex behaviour of nature. These theories must then be validated through experimentation. During an experiment, creativity must be used as it leads to the success of the experiment by improving the results and helping in new discoveries in science. Since results from experiments are more trustworthy and accurate, a scientific theory must be changed when discrepancies arise between experimental and theoretical results.

6.3 Point paradigm students' NOS views on probes 2, 7 and 13

An additional analysis was performed on probes 2, 7 and 13. The participants were first separated into two categories according to their beliefs on probe 2: either the view that nature has its own laws, or that scientists construct theories from observations. The different ideas expressed for probes 7 and 13, from each type of NOS reasoning for probe

2, were sorted. A similar procedure to that described in sections 6.2.1 and 6.2.2 was used to obtain and allocate the different NOS profiles to the students. Four main profiles emerged for students who use point reasoning and are as shown in Table 30.

Table 30: Profiles for students classified according to the point paradigm with the belief that nature has its own laws and scientists construct theories from observations.

	Profiles			
	Profile 1	Profile 2	Profile 3	Profile 4
Views on NOS for probes 7 and 13.	Scientists may use their creativity when undertaking experiments for new discoveries, improvements and to be successful. If experimental results and theories disagree, the experimental results are more accurate.	Scientists strictly use the scientific method when undertaking experiments as they must be successful and have accurate results. If experimental results and theories disagree, the experimental results are more accurate.	Scientists may use their creativity when undertaking experiments for new discoveries, improvements and to be successful. If experimental results and theories disagree, then both theories and experiments may be inaccurate.	Scientists strictly use the scientific method when undertaking experiments as they must be successful and have accurate results. If experimental results and theories disagree, then both theories and experiments may be inaccurate.

According to students with profile 1, the use of creativity is crucial in order to have a successful experiment whereby better experimental results will be obtained and new discoveries can be made in science. When there are discrepancies between experimental and theoretical results, the theory has to be changed as it is based on experimental results which are more accurate and reliable.

Profile 2 is characterised by the belief that the scientific method has to be used when conducting an experiment. It is an accurate method which ensures the success of an experiment by yielding trustworthy results. Consequently, when experimental and theoretical results do not agree, the theory must be revised.

Profile 3 is described by the view that creativity must be used during an experiment in order to improve the experimental results and increase the framework of scientific

knowledge. If there are mismatch between experimental and theoretical results, both the experiment and the theory must be checked as either may be inaccurate.

In profile 4, preference is given to the use of scientific method for conducting an experiment as better results and infallible knowledge will be obtained. However, when there are differences between experimental and theoretical results, both the theory and the experiment must be checked as the origin of the mistake cannot be ascertained.

A total of 121 students associated with the point paradigm answered probe 2, from which 64 are of opinion that nature has its own laws and 57 believe that scientists construct theories from observations. The students were unclassifiable when there were non-codeable views either for probe 7 or 13. The distribution of allocated profiles for students associated with the point paradigm with the view that nature has its own laws, and theories are inventions of the scientists are presented in Table 31.

Table 31: NOS profiles of students using the point paradigm.

		Students with the view that nature has its own laws. (n=64)	Students with the view that scientists construct theories. (n=57)	Total (n=121)
NOS profiles	Profile 1	32 (50%)	24 (42%)	56 (46%)
	Profile 2	11 (17%)	17 (30%)	28 (23%)
	Profile 3	6 (10%)	7 (12%)	13 (11%)
	Profile 4	4 (6%)	0 (0%)	4 (3%)
	Unclassifiable	11 (17%)	9 (16%)	20 (17%)
Total		64 (100%)	57 (100%)	121 (100%)

The data in Table 31 shows that from the 64 students who believe that nature has its own laws, half of the students (50%, 32 in 64) have the NOS views for probe 7 and 13 which are consistent with profile 1. Profile 2 was displayed by about one in six of the students in the sub-sample (11 in 64). The remaining profiles were displayed by a minority of the students, 10% and 6% respectively, for profile 3 and 4.

Less than half of the students with the opinion that theories are inventions of scientists have the NOS views for probes 7 and 13 which are described by profile 1 (42%, 24 in 57). Around 30% (17 in 57) of students in this sub-sample have the NOS beliefs which for probes 7 and 13 which are consistent with profile 2 and profile 3 described the NOS views of only 12% of the students.

Consequently, it was found that students classified according to the point paradigm with the view that nature has its own rules, believe that creativity is essential during an experiment as it guarantees better experimental results and new discoveries. Since a scientific theory is based on a scientific experiment, the theory must be changed when differences between experimental and theoretical results arise. However, for students associated with the point paradigm focussing on the belief that theories are inventions of the scientists, it is difficult to conclude if this category of students utilise two main trajectories for their views on probes 7 and 13 as the 12% difference which exists between profile 1 and profile 2 is considered insufficient to reach a constructive conclusion.

7. Conclusion

7.1 Summary of main findings

The findings of this study show that about three out of four undergraduate science students entering university use a predominant point paradigm for measurement decisions for data collection, data presentation and data comparison. This is very similar to findings reported elsewhere in the literature (see for example, Séré *et al.*, 1993; Rollnick *et al.*, 2001; Buffler *et al.*, 2001).

The results gathered from the present study indicate a considerable difference between the GEPS and mainstream students' views on measurement. The latter group more frequently uses a set paradigm (48%, 31 in 64) for measurement decisions compared to the GEPS cohort which has a high percentage (91%, 104 in 115) of students categorised according to the point paradigm. Hence, the outcomes of the present project are consistent with the results gathered from previous studies implemented on similar samples of students. These studies performed at the University of Cape Town on first year physics students' understanding of measurement were mainly on the GEPS students (Allie *et al.*, 1998; Buffler *et al.*, 2001; Lubben *et al.*, 2001) and have typically revealed that the majority of the GEPS students possess a dominant point paradigm view when they first arrive at university. Furthermore, a recent study carried out on 53 participants from the mainstream first year physics course showed that 34% of the mainstream students use point reasoning

only, while the majority (66%) use both types of paradigm when collecting, processing and comparing data (Volkwyn *et al.*, 2004).

The difference in the outcomes obtained for the GEPS and mainstream cohorts can be explained by the fact that GEPS students are mainly from educationally disadvantaged backgrounds. They had poor science teaching and little or no prior experience with experimental work at school level. Consequently, they do not have the required concepts and skills to deal with data. Contrary to the GEPS students, the mainstream students typically have a good academic background, better level of science understanding, proficiency in practical work and prior knowledge and skills to handle data.

The point and set paradigm model was used in earlier studies, for example, Buffler *et al.* (2001), Lubben *et al.* (2001) and Buffler *et al.* (2003), at the University of Cape Town. It was found to be a successful and reliable tool to identify, categorize and explain the actions and decisions of first year physics students' views on measurement when "doing" science. The various studies implemented on different backgrounds of students have yielded results which are consistent with one another. Furthermore, the paradigmatic model can be used to evaluate the effectiveness of new laboratory courses designed to shift students' views on measurement from dominant point to consistent set paradigm reasoning.

The findings also show that undergraduate science students generally prioritise experiments and experimental results. These two entities are regarded as the key for distinguishing between scientific and non-scientific knowledge. The acceptance or rejection of a theory is based solely on experimental evidence. The acquisition and construction of scientific knowledge and hence its reliability and validity are seen to be dependent on experiments and experimental results only. The majority of these undergraduate students' views on the relationship between scientific theories and experiments are consistent with the outcomes of separate studies performed on university students' beliefs of the interplay between these two entities (Ryder *et al.*, 1999; Ryder and Leach, 1999; Séré *et al.*, 2001). Furthermore, the undergraduate science students' views on the nature of scientific knowledge and purpose of scientific experiments are similar to those of secondary school students (Leach *et al.*, 1997) who refer to the applicability of

experiments for delineating between scientific and non scientific knowledge and mention that scientific experiments yield reliable evidence which are used to “evaluate” a theory.

The students in the present study seem to acknowledge the importance and inclusion of creativity when performing an experiment as compared to secondary school students (see for example Moss *et al.*, 2001) and even secondary school science teachers (Lederman, 1992; Abd-El-Khalick and Lederman, 2000; Mnisi and Dekkers, 2003) who do not recognise the use of creativity and imagination in science. Moreover, when the sample is probed about the origin of scientific laws and theories, roughly an equal percentage of the students are of opinion that the laws of nature already exist to be discovered (40%, 71 in 179) and believe that theories are constructed and invented by scientists, and hence involve human intervention (41%, 74 in 179).

Fairbrother and Hackling (1997), Hodson (1998) and Tsai (1998) argue that the actions and reasoning of students when engaged in experimental work is dependent on their views on the NOS. Furthermore, Séré *et al.* (2001) found that university and upper secondary students utilise different epistemological views of science when dealing with measurement in different scientific contexts. Consequently, it was proposed that students’ views on the NOS may be related to their views on the nature of scientific measurement.

The data collected in the present study were used to generate four different profiles for students’ views of the NOS. Analysis of the data in Table 23 (from chapter 6) shows that 78% of students using the point paradigm can be classified within three of these profiles, namely, profiles 1, 2 and 3. The same proportion of students using the set paradigm (71%) could be classified within two of these profiles, namely, profiles 1 and 3. Thus, the students categorised according to the set paradigm are the more coherent group than the group of students using the point paradigm. However, the outcomes of the present study seem to reveal that there is no statistically significant link between students’ views on the nature of measurement (the use of point or set paradigm) and their views of the NOS (their NOS profiles).

The majority of students categorised either according to the point or the set paradigm believe that experiments and experimental results are necessary for the generation of

scientific knowledge. According to them, experimental outcomes are more accurate and reliable than theories, and experiments are used to validate a hypothesis by providing evidence which prove whether it is correct. Consequently, a theory is subject to change when there are discrepancies between theoretical and experimental results as the theory is considered to be only a scientific claim. The acceptance or rejection of a theory is dependent on experimental evidence. Furthermore, the inclusion of creativity during an experiment was favoured by most of the students, although a sizable minority for users of both paradigms claims that the scientific method is the only appropriate experimental strategy. The main difference that exists between students associated with the point paradigm and the set paradigm is their beliefs on the origin of laws and theories. A higher percentage of students classified according to the set paradigm focus mainly on the notion that theories are inventions of the scientists. They mention that theories are constructed from observations and are then checked through experimentation. Students associated with the point paradigm also display a similar belief. However, their emphasis is also on the idea that a “true” knowledge exists. They believe that nature is made up of existing fixed patterns which need to be discovered through experimentation.

7.2 Limitations of the study

The validity of the data collection instrument was increased by using some questionnaire items (six out of eight measurement questions and two out of six NOS probes) which had been validated in previous studies. Careful and numerous piloting of the VASM questionnaire on different groups of respondents with different level of science understanding also increased the validity of the instrument and its administration. The use of three independent researchers for the development of the coding scheme for the questionnaire responses and the student profiles improved the validity of the data analysis method used. However, there are some limitations to the study.

Chi-squared tests were performed to determine whether there is a relationship between the views on the NOS and the views on the nature of scientific measurement. Usually, chi-squared analysis is applicable to large frequencies only (Linton, 2003). However, for the

present study, there were instances (for example, Table 27 in chapter 6) where the frequencies for the variables were less than five. Hence, the use of chi-squared tests in the main study was limited as for small frequencies the χ^2 values obtained are less valid.

The sample constitutes a higher percentage of students classified according to the point paradigm than students who use set reasoning. Consequently, when profiles were used and analysis was done on probes 2, 7 and 13, a larger proportion of students with point reasoning seem to be associated with the various NOS beliefs. A significant proportion of students associated with the point paradigm and the set paradigm are therefore required such that more substantial analysis can be made.

The GEPS students have a limited command of the English language compared to the mainstream students. This distinction was apparent in the two groups of students' understanding of probe 9 in the VASM questionnaire. Moreover, the GEPS students have poor science teaching and superficial laboratory experience. The two cohorts' views on measurement seem to coincide with their educational background. The GEPS students have mainly a point paradigm view while the mainstream students possess a mixture of both point and set paradigm reasoning with the latter being predominant.

7.3 Consequences for teaching

Even though the present study showed that there is no significant relationship between students' views on the NOS and their views on the nature of scientific measurement, it revealed that most of the students (classified either according to the point or set paradigm) prioritise experimental data (evidence) for the construction of scientific knowledge and for distinguishing between scientific and non-scientific knowledge. Furthermore, the revision of a theory over an experiment is favoured when experimental and theoretical results do not agree.

According to Ryder and Leach (1999), an understanding of measurement includes the ability to relate a scientific claim (theory) to the data (evidence) collected in an experiment.

Hence, during laboratory work, students are expected to demonstrate an understanding on the evaluation of evidence and interpretation of experimental data (Gott and Duggan, 1996). Millar (1996) describes the understanding of evidence as the ability to evaluate the effect of uncertainty on experimental data. However, Millar *et al.* (1994) argue that students' actions and decisions during experimental work is affected by their views on what constitute reliable experimental data and how they are related to a theory for the derivation of constructive scientific knowledge. Consequently, the inclusion of the NOS in laboratory work may help in developing the required understanding on the relationship between scientific claims and data. An opportunity may be created for the students to deal with "real" situations during laboratory work where theoretical and experimental results are in conflict, thus encouraging the students to perform the data analysis stage and relate the concept of uncertainty to the concept of evidence.

7.4 Future work

A study by Lubben *et al.* (2004) showed that students use different paradigms when dealing with measurement in the "everyday" and scientific contexts. They are more likely to be classified according to the set paradigm in the "everyday" than in the scientific domain. The underlying reasoning for using a set paradigm in the "everyday" context is derived from the nature of the instrument used. For the present study, on analysis of probe 6 in the VASM questionnaire, it was found that students mention the use of highly sophisticated apparatus and state that there are procedures to be followed when gathering measurements in science, with the result that the "exact" value can be obtained. In contrast, for the "everyday" domain, the students refer to the measurements made as rough estimates. They believe that the instruments used are not sensitive enough and recognise that there are many inaccuracies involved in measurements such that the value obtained will only be an approximation. Furthermore, the study by Lubben *et al.* (2004) showed that irrespective of the context, most of the students use the criterion "result-driven" when deciding whether to accept or reject a deviation in measurement. The "result-driven" criterion includes the idea whether the acceptance of the deviation will affect the outcome of the measurement to a large or small extent. Hence, the acceptability of discrepancies in

data is based on the students' views on the purpose of the "measuring" process being carried out.

According to the authors, when dealing with measurement in the "everyday" situation, students are more likely to use set reasoning and seem to accept variations in data more spontaneously. Consequently, it was concluded that students' use of "point" and "set" paradigm may be related to their views on the purpose of measurement. By implementing further research on the relationship between science students' views on the nature of scientific measurement and their views on the purpose of measurement, the origin of the point paradigm view and the motives that prompt students to use point reasoning can be explored.

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Appendix 1

The complete VASM questionnaire

Surname:

First name:

Student number:

VASM
January 2005

University of Cape Town

Department of Physics

Views About Scientific Measurement Questionnaire

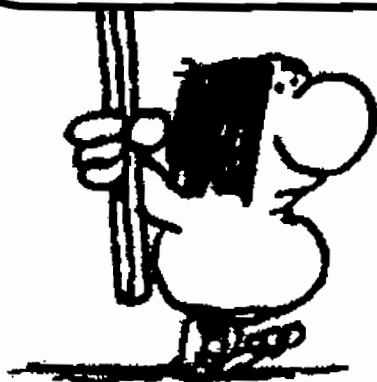
Instructions:

Write your name in the box above.
Inside this envelope there are pages
numbered from 1 to 14.

Answer the questions on each sheet.
It should take you no longer than
3 minutes to answer each question.
Answer the questions in order and
do not skip any sheet.

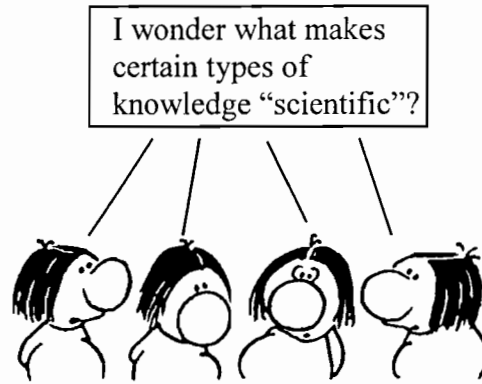
When you have completed a
question, put the sheet inside this
envelope and do not take it out
again, even if you want to change
your answer.

Never erase or change what you have
already written. Simply write any new
answers below the old ones.





1. You and a group of friends are discussing your views about the nature of **scientific knowledge**.



Write down a clear explanation of what you think **scientific knowledge** is.



2. You now think about what scientists do.

Nature follows exact laws and scientists discover these laws.

No, scientists construct theories to explain what they observe in nature.

I have another view which I will explain.

A B C

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

A	B	C
---	---	---

Explain your choice.



3. You continue to think about science.

New scientific knowledge is based on the results from scientific experiments.

No, new scientific knowledge can result from existing scientific theories.

I have a different idea.



A



B



C

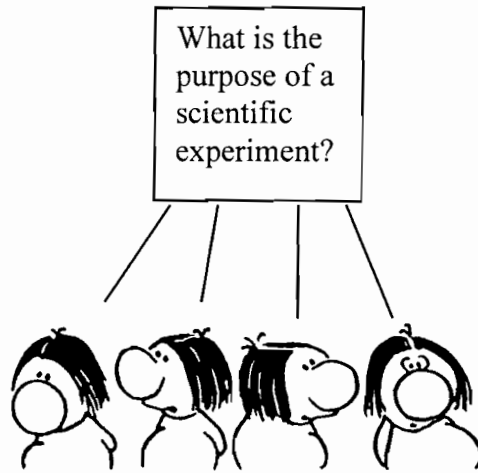
With whom do you most closely agree? (Circle ONE):

A	B	C
---	---	---

Explain your choice.



4. You and your friends now talk about scientific experiments.



Write down a clear explanation of what you think is the main purpose of a scientific experiment.



6. You now think about whether or not there is a difference between scientific measurements and measurements made in everyday life (for example: weighing the mass of a chemical produced in a chemistry experiment, compared to weighing some flour required for baking a cake).

Both scientific measurements and everyday measurements can be exact.

I think that scientific measurements can be exact, but everyday measurements are never exact.

No. Both scientific measurements and everyday measurements are never exact.

I have a different idea.



A



B



C



D

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

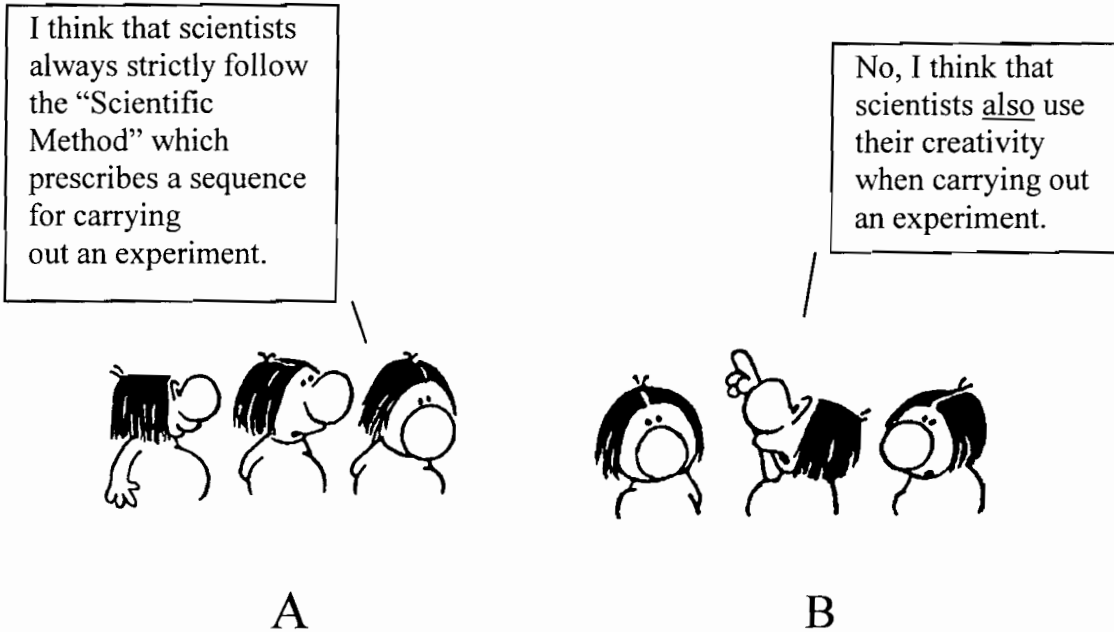
A	B	C	D
---	---	---	---

Explain your choice. In particular, explain carefully what you mean by “exact”.



You now decide that you should go and watch some scientists in action. You and your friends go to the local Magnetic Observatory where scientists make very sensitive measurements of the Earth's magnetic field and compare these measurements with theories about the composition of the centre of the Earth. You go into one of the laboratories where a group of scientists are busy with an experiment to measure the magnetic field of the Earth on that day.

7. You observe that the scientists are discussing what they should do in their experiment.



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

A	B
---	---

Explain your choice.

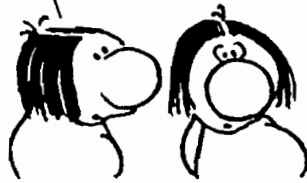


8. The scientists now start taking measurements. They first use a **very sensitive instrument** with a digital scale to measure the Earth's magnetic field. What they see is shown below.



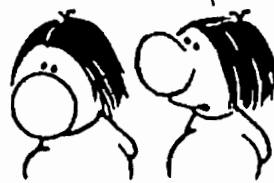
You discuss what the scientists now know about the Earth's magnetic field.

I think that the scientists now know that the Earth's magnetic field is exactly 0.137 mT.



A

I think that the scientists only have an approximate value of the Earth's magnetic field.



B

I don't agree with either of you.



C

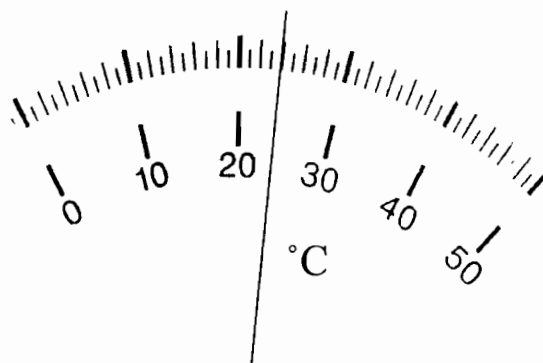
With which group do you most closely agree? (Circle ONE):

A	B	C
---	---	---

Explain your choice.



9. The scientists also need to know the temperature in the laboratory. They use a **special thermometer** and what they see on the display of the thermometer is shown below.



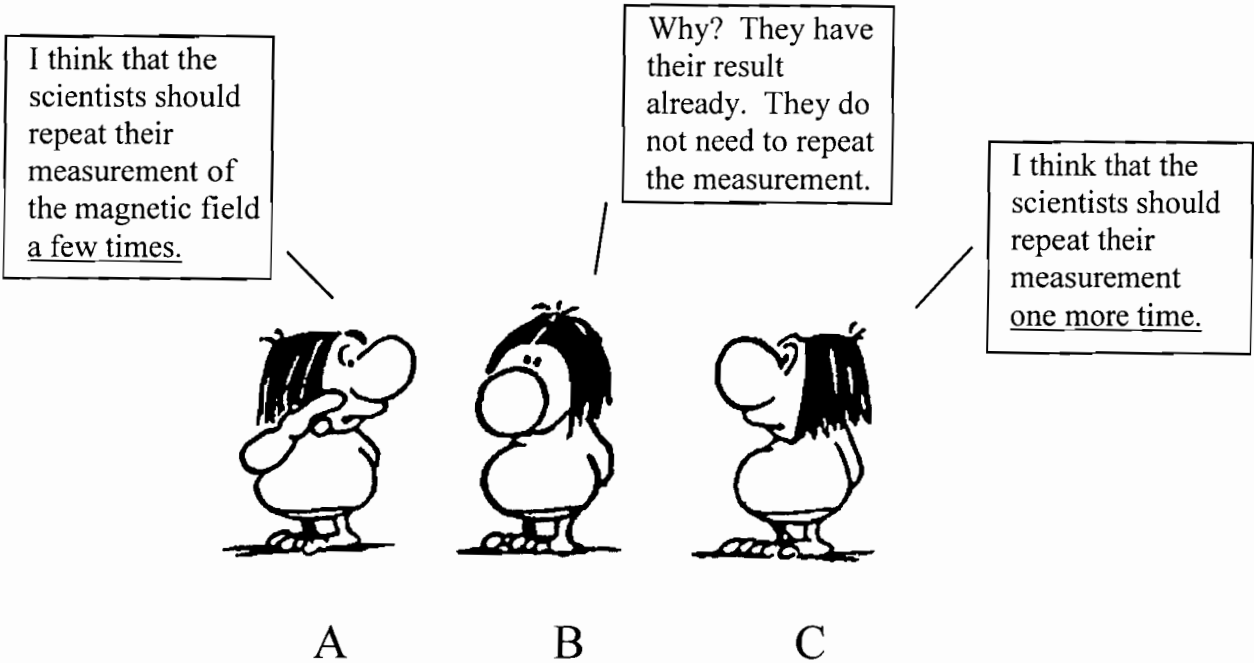
What is the temperature in the laboratory?

Explain your answer carefully.



10. You see that the scientists now discuss whether or not they should repeat their measurement of the magnetic field.

The following conversation now takes place among you.



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

A	B	C
---	---	---

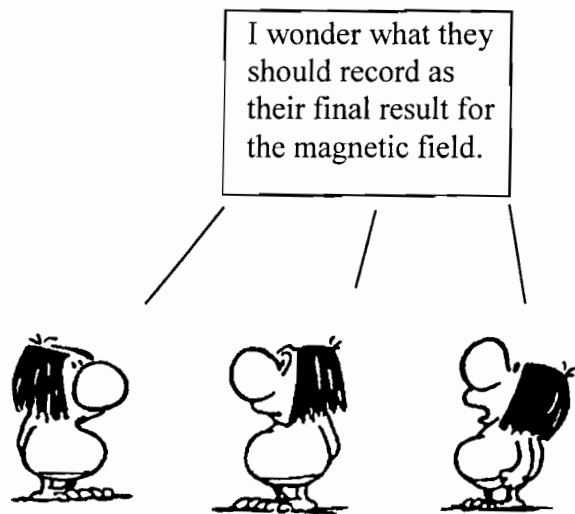
Explain your choice.



11. The scientists decide to repeat their measurement of the magnetic field five times. Their results are shown below.

<u>Measurement</u>	<u>Magnetic field (mT)</u>
1	0.137
2	0.128
3	0.138
4	0.128
5	0.134

You then discuss what the scientists should record as their final result for the magnetic field.



Write down what you think the scientists should record as their final result for the magnetic field.

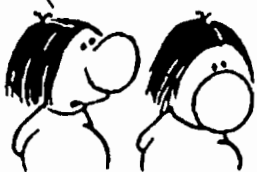
Explain your choice.



12. The scientists now decide to compare their results with the results obtained by another group of scientists for the same experiment. The data are shown below.

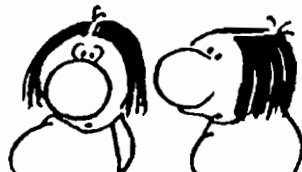
<u>Measurement</u>	<u>Group A</u> <u>Magnetic field (mT)</u>	<u>Group B</u> <u>Magnetic field (mT)</u>
1	0.137	0.128
2	0.128	0.140
3	0.138	0.134
4	0.128	0.127
5	0.134	0.126
Average:	0.133	0.131

The results of groups A and B agree with each other.



A

No, the results do not agree with each other.



B

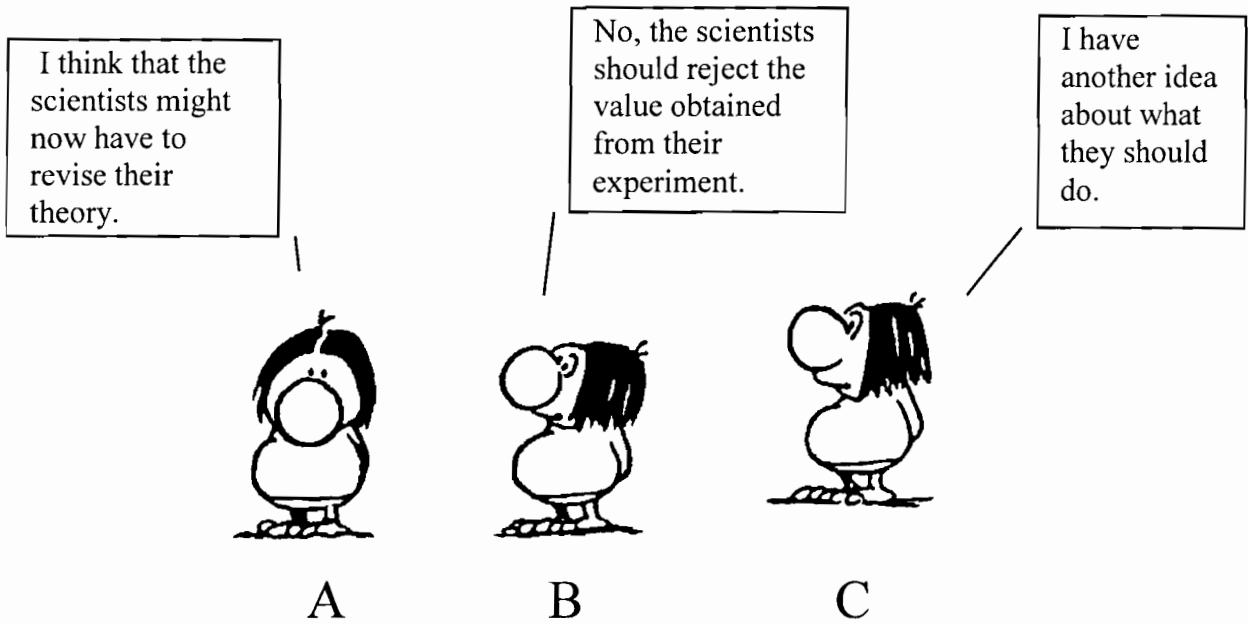
With which group do you most closely agree? (Circle ONE):

A	B
---	---

Explain your choice. Do not use the word "results" in your explanation.



13. After analysing their data, the scientists find that their measurement of the Earth's magnetic field does not agree with the value predicted by their theory. You discuss what the scientists should do.



With which group do you most closely agree? (Circle ONE):

A	B	C
---	---	---

Explain your choice.



14. Finally, you think about how the scientists may improve their measurement.

With enough money and the best equipment, the scientists can design an experiment that would give them the true value of the magnetic field.

That's not true! I think that the scientists will never know the true value of the magnetic field, no matter what they do.



A



B

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

A	B
---	---

Explain your choice.



18. Finally, please fill in these details:

Surname:		First names:	
Student number:			
Age:	Gender:	Male	Female
Home language:		Second language:	
Matric province:		Name of School:	

Tick the **subjects** that you did in **matric**. Enter HG or SG and your symbol.
If you did subjects that are not listed, write them in the spaces provided.

Subject	Tick	HG / SG	Symbol
English first language			
English second language			
Mathematics			
Physical Science			
Biology			
History			
Geography			
Afrikaans			

Which programme did you register on?	SCIB06	SCIB11	SCIB12	SCIB13	SCIB14
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The End



Appendix 2

The full version of the coding scheme for the VASM questionnaire

1. Views about the nature of scientific knowledge

N00 - No response

U00 - Not able to code response

	Frequency of codes	
A00	-	(no reason given).
A01	12	(not able to code response given).
A10	7	Scientific knowledge is based on facts.
A11	1	Scientific knowledge is obtained from observations.
A12	84	It is knowledge that explains/describes the behaviour of nature/system.
A13	-	It is knowledge that does not involve personal opinion/bias.
A14	-	Knowledge in science is concrete compared to other knowledge which is abstract.
A20	22	It involves experiments.
A21	13	It is knowledge based on evidence.
A22	9	It has to be proved by an experiment.
A23	6	It is obtained by using the scientific method.
A30	-	It is knowledge that can be modified/changed with new information.
A31	-	It is always being expanded/improved with new information.
A40	-	It includes human inference.
A41	3	It involves logic.
A42	-	It includes the use of creativity and imagination.
A43	-	The use of previous knowledge is also required.
A44	-	It is socially and culturally embedded.
A45	1	For knowledge to be considered as scientific it has to be validated by a scientific community.
A50	-	It has limitations. It is only an approximation of what is observed in nature.
A51	-	It is a model/representation of nature.
A60	3	It includes theories/laws.
A61	7	It involves calculations/mathematics/formulae.
A70	-	It leads to further predictions.
A71	2	It leads to improvements/provide solutions to problems.
A72	1	It is reliable/advanced/complex.
A80	4	It is knowledge obtained from maths/physics/biology/chemistry.

2. You now think about what scientists do

N00 - No response

U00 - Not able to code response

	Frequency of codes	
A		Nature follows exact laws and scientists <u>discover</u> these laws because...
A00	1	(no reason given).
A01	10	(not able to code response given).
A10	23	nature already has its laws/rules. Scientists have to research/prove and explain them.
A11	-	science deals with facts.
A12	-	science is about what is observed in nature.
A13	-	science is the quest for the truth about nature.
A14	-	scientists cannot change laws of nature.
A20	1	scientists need to provide reasons for the behaviour of nature.
A21	1	scientists explore and learn more about the laws/theories.
A30	-	scientists perform experiments to prove the laws or theories/the behaviour of nature.
A40	-	scientists help to improve the world/find solutions to problems. theories are simpler ways of putting together what scientists have gathered from experiments/nature/observations for better understanding.
A80	1	gathered from experiments/nature/observations for better understanding.
A90	1	scientists discover the laws of nature and also construct theories.
B		No, scientists <u>construct</u> theories to explain what they observed in nature because...
B00	2	(no reason given).
B01	10	(not able to code response given).
B10	12	nature already has its laws/rules. Scientists have to research/prove and explain them.
B20	13	scientists need to provide reasons for the behaviour of nature.
B21	2	scientists explore and learn more about the laws/theories.
B30	8	scientists perform experiments to prove the laws or theories/the behaviour of nature.
B31	4	research/experiments are used to explain/describe nature/a system.
B32	10	scientists experiment on what they observe and then formulate laws/theories on what will explain nature.
B33	-	experiments are used to predict phenomena.
B34	7	theories can change/improve with new information/as nature evolves.
B40	2	scientists help to improve the world/find solutions to problems.
B50	1	scientists model nature.
B51	-	scientists use mathematical model.
B52	16	the exact law is complex/cannot be obtained. A theory provides simpler explanation of what is observed in nature/from

		experiments.
B53	4	formulae/equations/mathematics/calculations are used.
B60	1	scientists use logic to explain nature.
B61	-	imagination and creativity are required.
B62	1	previous knowledge is also used.
B70	-	science is based on inventions.
B80	9	theories are simpler ways of putting together what scientists have gathered from experiments/nature/observations for better understanding.
C		I have another view which I will explain.
C00	-	(no reason given).
C01	2	(not able to code response given).
C10	6	Nature already has its laws/rules. Scientists have to research/prove and explain them.
C20	4	Scientists need to provide reasons for the behaviour of nature.
C30	6	Scientists perform experiments to prove the laws or theories/the behaviour of nature.
C31	1	Research/experiments are used to explain/describe nature/a system.
C32	1	Scientists experiment on what they observe and then formulate laws/theories on what will explain nature.
C33	-	Experiments are used to predict phenomena.
C34	1	Theories can change/improve with new information/as nature evolves.
C40	5	Scientists help to improve the world/find solutions to problems.
C50	1	Scientists model nature.
C52	1	The exact law is complex/cannot be obtained. A theory provides simpler explanation of what is observed in nature/from experiments.
C80	1	Theories are simpler ways of putting together what scientists have gathered from experiments/nature/observations for better understanding.
C90	9	Scientists discover the laws of nature and also construct theories.

3. You continue to think about science

N00 - No response

U00 - Not able to code response

	Frequency of codes	
A		New scientific knowledge is based on the results from <u>scientific experiments</u> because...
A00	2	(no reason given).
A01	4	(not able to code response given).
A10	-	experiments are used to support/test a hypothesis.
A11	12	experiments are used to prove a hypothesis/phenomenon.
A12	-	experiments can be used to falsify/disprove a hypothesis.
A14	-	experiments provide evidence.
A20	26	results from experiments are reliable/accurate.
A21	-	results from experiments are most reliable to construct laws.
A22	2	results from experiments are most reliable to construct theories/theorems.
A23	11	results from experiments provide more knowledge/information about what we are investigating/how nature works.
A24	-	experiments help scientists to choose among competing theories.
A25	-	traditionally experiments have been used to provide information/ to construct scientific knowledge.
A30	-	experiments reveal the truth about nature.
A31	-	experiments do not involve inaccuracies/assumptions.
A32	-	scientific method is used to do experiments.
A33	-	it is a process carried out carefully in the laboratory.
A34	2	highly sophisticated/sensitive apparatus are used.
A35	-	it leads to the required result.
A40	-	experiments lead to improvements.
A41	-	experiments provide solutions to problems.
A42	5	experiments lead to new discovery.
A50	1	science is based on experiments.
A62	1	scientific theories are always being improved/refined with new information/evidence.
A73	1	existing scientific theories can be used to design scientific experiments.
B		No, new scientific knowledge can result from existing <u>scientific theories</u>, because...
B00	2	(no reason given).
B01	5	(not able to code response given).
B11	4	experiments are used to prove a hypothesis/phenomenon.
B12	-	experiments can be used to falsify/disprove a hypothesis.
B13	3	the existing scientific theories have already been proved to be correct from past experiments.
B20	1	results from experiments are reliable/accurate.

B23	1	results from experiments provide more knowledge/information about what we are investigating/how nature works.
B34	3	highly sophisticated/sensitive apparatus are used.
B60	3	scientific theories are subject to change with accumulation of new information/evidence.
B61	-	scientific theories change when existing information is viewed in a new perspective.
B62	11	scientific theories are always being improved/refined with new information/evidence.
B70	-	existing scientific theories have firm/well established information.
B71	1	existing scientific theories can explain/predict a wide range of phenomenon.
B72	5	existing scientific theories provide a framework for current knowledge/future investigations.
B73	-	existing scientific theories can be used to design scientific experiments.
C		I have a different idea.
C00	-	(no reason given).
C01	5	(not able to code response given).
C11	9	Experiments are used to prove a hypothesis/phenomenon.
C12	-	Experiments can be used to falsify/disprove a hypothesis.
C13	2	The existing scientific theories have already been proved to be correct from past experiments.
C20	6	Results from experiments are more reliable/accurate.
C21	-	Results from experiments are most reliable to construct laws.
C22	2	Results from experiments are most reliable to construct theories/theorems.
C23	2	Results from experiments provide more knowledge/information about what we are investigating/how nature works.
C34	3	Highly sophisticated/sensitive apparatus are used.
C71	1	Existing scientific theories can explain/predict a wide range of phenomenon.
C80	43	Both scientific experiments and scientific theories are required.
C90	-	Inference is also used.
C91	-	Scientists use their creativity and imagination.
C92	-	Logical thinking is required.
C93	-	Previous knowledge is also used.
C94	-	Scientists model nature.
C95	-	Scientists use mathematical model.
C96	-	Scientists use formulae/equations.

4. You and your friends now talk about scientific experiments

N00 - No response

U00 - Not able to code response

	Frequency of codes	
A00	-	(no reason given).
A01	3	(not able to code response given).
A10	-	To reveal the exact cause/the truth about nature.
A11	15	To better explain/understand the behaviour of nature/ a theory.
A12	-	To model the laws of nature.
A20	60	To prove a hypothesis/phenomenon to be correct.
A21	-	To falsify/disprove a hypothesis.
A22	30	To prove whether a theory is correct or not.
A30	27	Results from experiments are more reliable/valid.
A31	1	Results from experiments are most reliable to construct laws.
A32	3	Results from experiments are most reliable to construct theories/theorems.
A33	20	Results from experiments provide more knowledge/information about what we are investigating/how nature works.
A34	-	Experiments help scientists to choose among competing theories.
A40	9	It leads to improvements/find solutions to problems.
A41	5	It leads to discoveries.
A50	3	Science is based on experiments.
A60	3	It helps to memorize scientific knowledge.

5. You continue to think about scientific measurement

N00 - No response

U00 - Not able to code response

		Frequency of codes	
A			Sometimes only <u>one</u> scientific measurement is sufficient for an <u>exact</u> result because...
A00	p	-	(no reason given).
A01	p	3	(not able to code response given).
A10	s	-	it depends on how sensitive the instrument is.
A11	p	-	scientific measurement uses highly sophisticated apparatus.
A12	p	-	the sensitivity of a scale cannot be changed indefinitely.
A13	p	-	technology is improving all the time.
A14	p	1	it depends on the type of instrument used. (A Vernier calliper/micrometer screw gauge will always yield the same value).
A20	p	1	it depends on the type of measurements/experiments. (If it is voltage of a battery, repeating the measurement will give the same result).
A30	p	1	it is useless to take multiple reading when the value is already known (from theory)/if the measurement is done carefully.
A31	p	2	it is useless to repeat measurement if the experiment is done under the same/required conditions.
A32	p	1	repeating is a waste of time/resources.
A40	p	-	repeating measurements yield a value close to the true value/the required value.
A41	p	1	repeating the measurements will yield the same and correct result.
A50	-	-	a reference scale is used.
A61	s	1	average reduces/eliminates errors.
B			No, for scientific measurement result to be <u>exact</u>, the experiment needs to be repeated <u>many</u> times and the average calculated because...
B00	-	1	(no reason given).
B01	-	6	(not able to code response).
B20	p	1	it depends on the type of measurements/experiments. (If it is voltage of a battery, repeating the measurement will give the same result).
B30	p	1	it is useless to take multiple reading when the value is already known (from theory)/if the measurement is done carefully.
B40	p	-	repeating measurements yield a value close to the true value/the required value.
B41	p	14	repeating to see if the measurements are same and correct.
B42	p	2	repeating measurements to choose the recurrent value.

B43	p	1	repeating give the recurrent values which are then chosen to get an average.
B44	p	11	repeating to get values close to one another/to get a pattern.
B45	p	21	repeating to make sure of the value obtained.
B46	p	11	repeating to reduce/eliminate errors.
B47	p	20	repeating makes the result/value more accurate.
B48	p	3	repeating to get the right/true value.
B49	p	1	measurements must be repeated (no reasons provided)
B60	s	-	average reduces differences/uncertainties among readings.
B61	s	10	average reduces/eliminates errors.
B62	p	4	average gives a value close to the true/required value.
B63	s	2	average yields the best approximate.
B64	s	9	average gives a better value/more accurate value.
B65	s	-	average gives a value which lies within an interval.
B66	p	1	average yield the exact value.
B70	s	-	measurements taken under the same/different experimental/environmental conditions yields different readings.
B71	s	-	measurement involves judgement.
B72	s	4	experiments/measurements are affected by external factors/measuring process.
B73	s	1	variations in measurement occur.
B75	s	3	measurements/experiments/apparatus used always involve errors/inaccuracies.
C			I have another idea.
C00	-	-	(no reason given).
C01	-	-	(not able to code response).
C10	s	-	It depends on how sensitive the instrument is.
C11	p	-	Scientific measurement uses highly sophisticated apparatus.
C12	s	-	The sensitivity of a scale cannot be changed indefinitely.
C13	p	-	Technology is improving all the time.
C14	p	-	It depends on the type of instrument used. (A Vernier calliper/micrometer screw gauge will always yield the same value).
C20	p	5	It depends on the type of measurements/experiments. (If it is voltage of a battery, repeating the measurement will give the same result).
C31	p	1	It is useless to repeat measurement if the experiment is done under the same/required conditions.
C40	p	1	Repeating measurements yield a value close to the true value/the required value.
C41	p	5	Repeating to see if the measurements are same and correct.
C42	p	4	Repeating measurements to choose the recurrent value.
C43	p	1	Repeating give the recurrent values which are then chosen to get an average.
C45	p	2	Repeating to make sure of the value obtained.
C47	p	1	Repeating makes the result/value more accurate.
C60	s	-	Average reduces differences/uncertainties among readings.

C61	s	3	Average reduces/eliminate errors.
C62	p	3	Average gives a value close to the true value.
C63	s	1	Average yields the best approximate.
C64	s	2	Average gives a better value/more accurate value.
C70	s	1	Measurements taken under the same/different experimental/environmental conditions yields different readings.
C71	s	1	Measurement involves judgement.
C72	s	2	Measurements are affected by external factors.
C73	s	-	Variations in measurement occur.
C74	s	1	Only the best approximate can be obtained.
C75	s	1	Measurements/experiments/apparatus used always involve errors/inaccuracies.
C80	s	2	Repeating will give an accurate measurement with its uncertainty value.
C81	s	-	The uncertainty value can never be zero.

6. You now think about whether or not there is a difference between scientific measurements and measurements made in everyday life

N00 - No response

U00 - Not able to code response

Frequency of codes		
A		<u>Both</u> scientific measurements and everyday measurements can be exact because...
A00	-	(no reason given).
A01	4	(not able to code response given).
A10	p 7	the same/reliable/highly sophisticated apparatus is used.
A11	p 7	it depends on the quality/accuracy of the apparatus being used.
A12	p 3	scientific measurements deal with highly sophisticated/accurate instruments.
A20	p -	both lead to reliable/true conclusions/values.
A21	p -	both give the same/expected/required value.
A30	p 2	both give a value which is close to the true value.
A31	s 1	both give the best approximate.
A32	s -	both give a value which lies within a range.
A40	s 2	both depend on the accuracy/judgement of the individual.
A50	p 3	in both cases, measurement must be repeated.
A51	s -	in both cases, measurement must be repeated to get an average.
A52	p -	in both cases, measurement must be repeated to get closer to the true value.
A53	p -	in both cases, measurements are repeated and the recurrent value is selected.
A54	p -	repeating the measurement will give the same value.
A60	p 2	both can be exact but scientific measurement is more precise/accurate than everyday measurement.
A61	s -	both are inexact but scientific measurement is more precise/accurate than everyday measurement.
A70	- 1	it depends on the purpose of measurement whether or not it will affect the quantity or quality of the product obtained.
A71	- 3	it depends on how the process/measurement was carried out.
A80	- 4	science is everywhere.
A81	p -	science is built on exactness.
A82	p -	science yields the truth.
A84	p 2	in science, exact values are required as they are needed for further calculations/to be successful in a scientific endeavour.
A86	p 1	in both cases, we need to be successful.
A87	- 1	scientific measurement require a step by step process/scientific method.
B		I think that scientific measurements can be exact, but everyday measurements are <u>never</u> exact because...
B00	- -	(no reason given).

B01	-	1	(not able to code response given).
B11	p	-	it depends on the quality/accuracy of the apparatus being used.
B12	p	9	scientific measurements deal with highly sophisticated/accurate instruments.
B13	p	-	scientific experiments use electronic device to get an exact answer.
B14	-	-	everyday measurements use an analogue scale.
B22	p	-	scientific measurement must yield better/exact results/the required value.
B33	p	2	scientific measurements give a value close to the true value.
B41	p	12	everyday measurements are rough estimates/depend on the judgement of the individual.
B55	p	3	in science, measurements must be repeated.
B56	s	-	scientific measurements are repeated to get an average.
B57	p	-	scientific measurements are repeated to get closer to the true value.
B58	p	-	scientific measurements are repeated and the recurrent value is chosen.
B60	p	-	both are exact but scientific measurement is more precise/accurate than everyday measurement.
B61	s	-	both are inexact but scientific measurement is more precise/accurate than everyday measurement.
B70	-	2	it depends on the purpose of measurement whether or not it will affect the quantity or quality of the product obtained.
B71	p	1	both can be exact depending on how the process/measurement was carried out.
B81	p	-	science is built on exactness.
B82	p	2	science yields the truth.
B83	-	-	scientific measurement is a process carried out in the laboratory.
B84	p	3	in science, exact values are required as they are needed for further calculations/to be successful in a scientific endeavour.
B85	-	-	scientific measurement makes use of a reference scale.
B87	-	-	scientific measurement require a step by step process/scientific method.
B90	s	-	scientific measurements always have an uncertainty value associated with it.

C

No. Both scientific measurements and everyday measurements are never exact because...

C00	-	1	(no reason given).
C01	-	4	(not able to code response given).
C11	p	-	it depends on the quality/accuracy of the apparatus being used.
C30	p	1	both give a value which is close to the true value.
C31	s	-	both give the best approximate.
C32	s	-	both give a value which lies within a range.
C40	s	2	both depend on the accuracy/judgement of the individual.
C41	p	2	everyday measurements are rough estimates/depend on the judgement of the individual.
C42	s	34	both involve inaccuracies/errors/assumptions.
C43	s	1	both are affected by external factors.
C44	s	1	variations have to occur.

C45	s	4	the instrument have limitations/inaccuracies.
C61	s	6	both are inexact but scientific measurement is more precise/accurate than everyday measurement.
C62	-	1	scientific measurement is more precise/accurate than everyday measurement.
C70	-	-	it depends on the purpose of measurement whether or not it will affect the quantity or quality of the product obtained.
C90	s	-	scientific measurements always have an uncertainty value associated with it.
C91	s	-	both have an uncertainty value associated.
D			I have a different idea.
D00	-	-	(no reason given).
D01	-	2	(not able to code response given).
D11	p	2	It depends on the quality/accuracy of the apparatus being used.
D12	p	3	Scientific measurements deal with highly sophisticated/accurate instruments.
D22	p	1	Scientific measurement must yield better/exact results/the required value.
D23	p	1	It depends if in both cases the same value is obtained.
D31	s	1	Both give the best approximate.
D33	p	1	Scientific measurements give a value close to the true value.
D34	s	-	Scientific measurement gives the best approximate.
D35	s	-	Scientific measurement gives a value which lies within a range.
D40	s	2	Both depend on the accuracy/judgement of the individual.
D41	p	2	Everyday measurements are rough estimates/depend on the judgement of the individual.
D42	s	4	Both involve inaccuracies/errors/assumptions.
D43	s	-	Both are affected by external factors.
D50	p	1	In both cases, measurement must be repeated.
D60	p	2	Both are exact but scientific measurement is more precise/accurate than everyday measurement.
D61	s	1	Both are inexact but scientific measurement is more precise/accurate than everyday measurement.
D62	-	3	Scientific measurement is more precise/accurate than everyday measurement.
D70	-	5	It depends on the purpose of measurement whether or not it will affect the quantity or quality of the product obtained.
D71	p	6	Both can be exact depending on how the process/measurement was carried out.
D72	p	2	Everyday measurements can be exact depending on how the process was carried out.
D73	p	1	Scientific measurements can be exact depending on how the process was carried out.
D82	p	2	Science yields the truth.
D84	p	2	In science, exact values are required as they are needed for further calculations/to be successful in a scientific endeavour.
D87	p	1	Both need to follow the given instructions.
D88	-	1	An exact measurement can never be obtained.

7. The scientists are discussing what they should do in their experiment

N00 - No response

U00 - Not able to code response

Frequency of codes		
A		I think that scientists always strictly follow the “Scientific Method” which prescribes a sequence for carrying out an experiment because...
A00	-	(no reason given).
A01	2	(not able to code response given).
A10	-	“Scientific method” is a traditional way of “doing” science.
A11	1	“Scientific method” has been proved to always yield trustworthy and logical results.
A20	3	science involves laws and procedures which need to be followed.
A21	3	it is the best/accurate method.
A30	-	science is complex. We use “Scientific method” to obtain reliable results/knowledge.
A40	1	we need to have values close to one another.
A41	32	we need to be successful in our experiment/have consistency in our results/get reliable and accurate knowledge.
A42	6	we need to get the expected/required value.
A50	1	scientists use their creativity only when planning the experiment but use the “Scientific method” to do the experiment.
A51	-	scientists use their creativity only when interpreting their results/ formulating a conclusion.
A90	1	the use of creativity can lead to further discovery.
A92	-	scientists use scientific method to improve their experiment/results.
A93	-	scientific method lead to further discovery.
B		No, I think that scientists <u>also</u> use their creativity when carrying out an experiment because...
B00	-	(no reason given).
B01	10	(not able to code response given).
B20	1	science involves laws and procedures which need to be followed.
B40	-	we need to have values close to one another.
B41	12	we need to be successful in our experiment/have consistency in our results/get reliable and accurate knowledge.
B42	3	we need to get the expected/required value.
B50	2	scientists use their creativity only when planning the experiment but use the “Scientific method” to do the experiment.
B51	3	scientists use their creativity only when interpreting their results/ formulating a conclusion.
B52	6	of unexpected problems while doing the experiment.
B54	2	the scientific method can be faulty.
B55	1	experiments involve the use of logic.
B56	1	creativity is required to have new knowledge.

B60	12	depending on the type of experiments scientists design and develop their own procedure which is most suitable for them to do the experiment.
B70	-	“Scientific method” is a way of reporting a research/experiment such that knowledge is meaningful and accessible to everyone.
B80	3	scientists also use previous knowledge/theories when doing an experiment.
B90	48	the use of creativity can lead to further discovery.
B91	23	scientists use creativity for improvements.
B94	1	the use of imagination and creativity help to solve problems.

8. The scientists now start taking measurements. They first use a very sensitive instrument with a digital scale to measure the Earth's magnetic field

N00 - No response

U00 - Not able to code response

	Frequency of codes	
A		
I think that the scientists now know that the Earth's magnetic field is <u>exactly</u> 0.137 mT because...		
A00 p	-	(no reason given).
A01 p	1	(not able to code response given).
A10 p	14	a sensitive digital metre is used.
A11 p	-	the instrument is at its maximum sensitivity.
A12 p	1	the scale shows 3 digits after the decimal.
A16 -	2	it is what is shown by the instrument.
A20 p	-	a digital metre does not require judgement when taking a reading.
A21 p	-	measurements always yield an exact number.
A22 p	-	science needs exact value which will be used to perform further calculations.
A30 p	-	repeating the experiment will yield different value.
A34 p	1	repeating the measurement to see if the same value is obtained.
B		
I think that the scientists only have an <u>approximate</u> value of the Earth's magnetic field because...		
B00 -	1	(no reason given).
B01 -	2	(not able to code response given).
B10 p	2	a sensitive digital metre is used.
B13 s	2	changing the sensitivity of the digital metre will give more accurate value.
B14 s	-	use of different instruments will give different values.
B15 s	10	it depends on how accurate the instrument is.
B23 p	-	science is exact but measurement is inexact and hence use "approximate".
B24 -	3	in science, only an approximation can be obtained.
B30 p	2	repeating the experiment will yield different value.
B31 p	25	measurement must be repeated many times/they have only 1 reading.
B32 p	-	many measurements need to be taken and the recurrent value selected.
B33 s	4	many measurements must be taken and get an average.
B34 p	3	repeating measurements to see if the same results are obtained.
B35 p	1	repeating will give values which are close to one another.
B36 p	-	many measurements must be taken to obtain an exact value.
B37 s	2	it is only the average value.
B38 -	-	the experiment must be repeated with different instrument to be more accurate.
B40 s	13	the value has been rounded off.

B50	s	11	measurements involve inaccuracies/errors.
B51	-	2	the apparatus is created by humans/may be faulty.
B52	s	27	experiments/measurements are affected by external factors/measuring process.
B53	s	1	judgement/estimation is required.
B54	s	11	there are some degree of inaccuracy in the apparatus.
B60	p	4	measurements always yield values close to the true value.
B61	p	-	only values close to one another can be obtained.
B70	s	-	measurements always yield the best estimate.
B71	s	1	the value of the magnetic field lies within a range.
B72	s	1	the scientists have the most accurate value.
B80	s	1	a reading has an uncertainty value associated with it is meaningless.
C			I don't agree with either of you because...
C00	-	-	(no reason given).
C01	-	2	(not able to code response given).
C10	p	2	a sensitive digital metre is used.
C13	s	-	the sensitivity of the digital metre can be changed to give more accurate value.
C14	s	-	use of different instruments will give different values.
C15	s	-	it depends on the accuracy of the instrument.
C20	p	-	a digital metre does not require judgement when taking a reading.
C31	p	8	measurement must be repeated many times/they have only 1 reading.
C32	p	1	many measurements need to be taken and the recurrent value selected.
C33	s	5	many measurements must be take and get an average.
C34	p	2	repeating measurements to see if the same results are obtained.
C35	p	-	repeating will give values which are close to one another.
C36	p	-	many measurements must be taken to obtain an exact value.
C38	-	-	the experiment must be repeated with different instrument.
C50	s	-	measurements involve inaccuracies/errors.
C51	-	-	the apparatus is created by humans/may be faulty.
C52	s	6	experiments/measurements are affected by external/measuring process.
C53	s	1	judgement/estimation is required.
C60	p	-	measurements always yield values close to the true value.
C62	p	2	it is a value closed to the true/exact value.
C70	s	-	measurements always yield the best estimate.
C72	s	1	the scientists have the most accurate value.
C80	s	-	a reading without an uncertainty value associated with it is meaningless.

9. The scientists also need to know the temperature in the room in order to calibrate their results. They use a special thermometer

N00 - No response

U00 - Not able to code response

	Frequency of codes	
A		The temperature is <u>exact</u> because...
A00 p	1	(no reason given).
A01 p	7	(not able to code response given).
A10 p	24	this is what is shown by the analogue scale.
A11 p	2	the analogue thermometer is very sensitive.
A20 p	-	science is built on exactness.
A21 -	-	scientific method was used to carry out the experiment.
A22 p	-	repeating the experiment under the same conditions will yield the same result.
A30 p	68	the needle is on the 24 degree mark.
A31 s	2	the value for temperature lies within an interval.
A32 -	10	it is the ideal temperature required for a laboratory/to carry out an experiment.
A41 p	4	it is a value close to the room temperature/the required value.
A42 p	1	it should not exceed the room temperature.
A43 p	3	it is a value less than the room temperature.
A44 p	2	it is the room temperature of the laboratory.
A60 s	4	experiments/measurements are affected by external/measuring process.
A61 s	1	there are many errors/inaccuracies associated with measurement.
A80 p	1	measurements must be repeated (no reason provided).
B		The temperature is <u>approximate</u> because...
B00 s	-	(no reason given).
B01 s	3	(not able to code response).
B12 s	6	it depends on the accuracy of the thermometer.
B13 -	4	analogue scale/thermometer needs to be divided into more divisions.
B14 -	-	more calibrations will reduce uncertainty.
B15 s	3	more calibrations will lead to more accurate reading.
B16 p	-	more calibrations will yield the exact value.
B23 p	-	science is exact but measurement is inexact and hence use "approximate".
B24 s	-	an exact reading cannot be obtained. We just have the best estimate.
B25 -	-	in science, an "exact" value/result does not exist.
B26 p	-	an exact temperature can only be obtained by using a digital scale.
B30 -	2	the needle is on the 24 degree mark.
B31 s	-	the value for temperature lies within an interval.
B40 p	-	measurement is about yielding a value close to the true value.

B41	p	-	it is a value close to the room temperature/the required value.
B50	s	-	an average will give a better/more accurate value.
B60	s	18	experiments/measurements are affected by external/measuring process.
B61	s	7	there are many errors/inaccuracies associated with measurement.
B62	s	1	use of analogue scale is never accurate.
B63	s	2	the value has been rounded off.
B70	p	-	temperature should be measured using a different thermometer and results compared.
B80	p	-	measurements must be repeated (no reason provided).
B81	p	-	many measurements must be taken and the most recurrent value chosen.
B90	s	1	a measurement result has an uncertainty value associated with it.
B91	s	-	the uncertainty cannot be reduced to zero.

C

The temperature lies within an interval/a range of temperature because....

C00	s	-	(no reason given).
C01	s	1	(not able to code response).
C12	s	-	it depends on the accuracy of the thermometer.
C13	-	-	analogue scale/thermometer needs to be divided into more divisions.
C14	-	-	more calibrations will reduce uncertainty.
C15	s	-	more calibrations will lead to more precise/accurate reading.
C16	p	-	more calibrations will yield the exact value.
C25	-	-	in science, an "exact" value/result does not exist.
C30	-	-	the needle is on the 24 degree mark.
C31	s	-	the value for temperature lies within an interval.
C32	-	-	it is the ideal temperature required for a laboratory.
C40	p	-	measurement is about yielding a value close to the true value.
C41	p	1	it is a value close to the room temperature/the required value.
C50	s	-	an average will give a better/more accurate value.
C60	s	-	experiments/measurements are affected by external/measuring process.
C61	s	-	there are many errors/inaccuracies associated with measurements.
C90	s	-	a measurement has an uncertainty value associated with it.
C91	s	-	the uncertainty cannot be reduced to zero.

10. The scientists discuss whether or not they should repeat their measurement of the magnetic field

N00 - No response

U00 - Not able to code response

	Frequency of codes	
A		I think that the scientists should repeat their measurement of the magnetic field <u>a few times</u> because...
A00 -	-	(no reason given).
A01 -	-	(not able to code response).
A10 p	1	repeating for practice.
A11 p	-	practice will produce more accurate or better measurement.
A12 p	-	practice will reduce the systematic error in measurement.
A20 p	10	repeating gives readings which are close together/to get a pattern.
A21 p	22	repeating to be sure/confirm the results.
A22 p	6	repeating to get an exact/required value.
A23 p	11	repeating reduces/eliminates errors.
A24 p	31	repeating gives a more accurate/better measurement.
A25 p	3	repeating to get closer to the true value.
A30 s	21	more readings needed to get an average.
A31 s	9	to get a more accurate/reliable average.
A32 s	-	to get an average and a spread/uncertainty.
A33 s	-	to get an average and a better/narrower spread/uncertainty.
A34 p	4	to get an average in order to get closer to the true value.
A35 s	3	to get an average which reduce errors.
A36 p	1	the values which are close to one another must be selected to calculate the average value.
A40 p	29	repeating may give the same and correct answer.
A50 p	1	to get a variety of results.
A60 p	5	repetition is necessary (no reason provided).
A61 s	-	you must always get three measurements.
A70 s	1	the spread/uncertainty must be determined.
A71 p	-	a better/narrower spread/uncertainty must be determined.
A72 s	-	the uncertainty must be determined to get closer to the true value.
A80 s	2	experiment/measurements are affected by external/measuring process.
B		Why? They have their result already. They do not need to repeat the measurement because...
B00 -	-	(no reason given).
B01 p	-	(not able to code response).
B40 p	-	repeating may give the same and correct answer.
B51 p	1	repeating is a waste of time/resources.
B53 p	-	repeating will give different results which is confusing/faulty.

C		I think that the scientists should repeat their measurement <u>one more time</u> because...
C00	-	(no reason given).
C01	1	(not able to code response).
C11	p	practice will produce more accurate or better measurement.
C12	p	practice will reduce the systematic error in measurement.
C20	p	1 repeating gives readings which are close together.
C24	p	3 repeating gives a more accurate/better measurement.
C30	s	- more readings needed to get an average.
C31	s	- to get a more accurate/reliable average.
C40	p	9 repeating may give the same and correct answer.
C50	p	- to get a variety of results.
C51	p	3 repeating is a waste of time/resources.
C52	p	- many repeats are desirable, but time consuming.
C90	p	- the value will keep on changing.

11. The scientists decide to repeat their measurement of the magnetic field five times

N00 - No response

U00 - Not able to code response

	Frequency of codes	
A		
0.128 mT.		
A00 -	-	(no reason given).
A01 -	1	(not able to code response).
A10 p	41	It appears twice in the set of values.
A20 p	-	It is the exact value.
A30 s	-	It is the average value.
A40 p	-	It is closest to the average value.
A50 s	-	It is the median value.
A91 -	1	It is the minimum value.
B		
0.133 mT.		
B00 -	-	(no reason given).
B01 -	-	(not able to code response).
B30 s	82	It is the average value.
B31 p	3	The value obtained by excluding the highest and lowest value.
B40 p	-	It is closest to the average value.
B41 p	1	It is close to 0.128 mT which occur twice.
B42 p	-	It is closed to the last value (0.134 mT) obtained after much practice.
B43 p	-	It is the best estimate.
B50 s	1	It is the median value.
C		
0.134 mT.		
C00 -	-	(no reason given).
C01 -	-	(not able to code response).
C30 s	9	It is the average value.
C40 p	5	It is closest to the average value.
C41 p	2	It is close to the other values.
C50 s	-	It is the median value.
C60 p	1	It is the last measurement and hence more accurate as it has been obtained after practising five times.
C80 p	3	It is the middle measurement.
D		
0.137 mT.		
D00 -	-	(no reason given).
D01 -	-	(not able to code response).
D30 s	1	It is the average value.
D40 p	-	It is closest to the average value.
D43 p	1	It is close to the third value obtained (0.138 mT).
D50 s	-	It is the median value.
D61 p	-	It is the first measurement obtained for the magnetic field and hence more accurate.

E		0.138 mT.
E00	-	(no reason given).
E01	-	(not able to code response).
E30	s	1 It is the average value.
E40	p	- It is closest to the average value.
E44	p	- It is close to the first value obtained (0.137 mT).
E50	s	- It is the median value.
E90	p	1 It is the highest value.
F		Other
F00	-	(no reason given).
F01	-	(not able to code response).
F11	p	3 The recurrent value must be chosen.
F45	p	3 Choose a value which is close to the remaining values/one another.
F70	s	8 Calculate the average.
F71	p	3 Choose the values which are close to one another and calculate the average.
F72	-	- Calculate the sum of all five measurements.
F73		1 Take a range of values.
F81	p	1 It is the middle value.

12. The scientists now decide to compare their results with the results from an experiment on magnetic fields completed by another group of scientists

N00 - No response

U00 - Not able to code response

	Frequency of codes	
A		The results of groups A and B <u>agree</u> with each other because...
A00 -	-	(no reason given).
A01 -	-	(not able to code response given).
A10 p	56	the average value for both groups are more or less the same.
A11 p	9	the average value for both groups are more or less the same, the difference is due to external (environmental/experimental) factors.
A12 p	-	the average value for both groups are more or less the same, both being close to the true value of the magnetic field.
A13 p	6	the average value for both groups are close to each other and in any experiment a difference will always exist.
A14 p	20	the average values are more or less the same, the small difference is negligible.
A15 p	13	on rounding off, the averages are more or less the same/the same values are obtained.
A20 p	5	the readings/measurements for both sets are more or less the same.
A21 p	3	the readings/measurements for both sets have the same spread.
A22 s	1	the readings/measurements have an overlapping spread.
A23 p	-	group A readings are much closer to one another.
A24 p	10	some/most measurements of group A repeat themselves in group B.
A28 p	1	the recurrent measurement/reading should be selected.
A30 s	1	the uncertainties of the averages may overlap.
A31 s	1	the averages are more or less the same with similar ranges/spreads.
A32 p	-	the uncertainties for both groups are close to each other.
A33 s	-	the uncertainties for both group overlap.
A44 p	2	the average lies between the range of measurement obtained in group A and group B.
B		No, the results <u>do not agree</u> with each other because...
B00 -	-	(no reason given).
B01 -	4	(not able to code response given).
B10 p	2	the average value for both groups are more or less the same.
B22 s	1	the spread for both set of measurements is different.
B23 s	-	the spread for both averages is different.
B25 p	1	only two of the readings repeat themselves in both groups.
B26 p	14	the measurement/reading is different.
B27 p	-	the average is different and only 2 of the readings repeat themselves in both group.
B34 s	-	the uncertainties do not overlap.
B35 s	-	the uncertainties for both set of measurement need to be calculated to know whether they overlap.

B40 p	16	the average is different in both cases.
B41 p	1	the average is different as the experiment is affected by external (experimental/environmental).
B42 p	-	the average is different and the true/exact value cannot be known.
B43 p	7	for the two groups to agree, the average should be the same in both cases.
B50 p	-	the two groups will only agree if the average value obtained in each case appears as one of the measurement.
B60 p	3	absolute accuracy/identical results are required to agree.

13. The scientists find that the result from their experiment does not agree with the value predicted by their theory

N00 - No response

U00 - Not able to code response

	Frequency of codes	
A		I think that the scientists might now have to revise their theory because...
A00	-	(no reason given).
A01	8	(not able to code response given).
A10	15	results from experiments are more reliable/accurate.
A11	-	results from experiments are more reliable to construct a theory.
A12	37	the value predicted by theory may be faulty/inaccurate.
A13	1	experiments reveal the truth about nature/give the true value.
A14	-	scientific method was used to carry out the experiment.
A15	-	scientific experiments make use of highly accurate instrument.
A20	10	theory is based on experiments which prove whether it is right or wrong.
A21	5	the experiment has proved that the theory is wrong.
A30	5	theories are always being improved/refined with new evidence/information.
A31	2	theories are subject to change with the accumulation of new information.
A40	1	the experiment must be repeated.
A41	2	the theory must be changed if on repeating the experiment (after checking the theory using different/improved conditions/apparatus), the result obtained does not match theory.
A42	1	on repeating the experiment, both values must match.
A44	2	the experiment must be repeated after revising the theory.
A50	1	theory can never change. It has been proved by earlier experiments.
A60	1	experiments/measurements have approximations/inaccuracies.
A90	2	check both the theory and experiment.
A92	1	if on checking the experiment, no fault is found.
B		No, the scientists should reject the value obtained from their experiment because...
B00	-	(no reason given).
B01	-	(not able to code response given).
B23	-	the theory must be proved by the experiment.
B41	1	the theory must be changed if on repeating the experiment (after checking the theory using different/improved conditions/apparatus), the result obtained does not match theory.
B50	1	theory can never change. It has been proved by earlier experiments.
B60	-	experiments/measurements have approximations/inaccuracies.

B61	1	experiments/measurements are affected by external factors(environmental/experimental factors).
B62	-	measurements/experiments depend on the sensitivity of the apparatus.
B63	-	measurements/experiments depend on the judgement of scientists.
B70	-	new scientific knowledge can originate from scientific theories only.
B71	-	previous knowledge in this field has been used to construct the theory.
B72	-	the theory has a greater explanatory power than the experiment.
C		I have another idea about what they should do.
C00	-	(no reason given).
C01	6	(not able to code response given).
C10	3	Results from experiments are more reliable/accurate.
C12	6	The value predicted by theory may be faulty/inaccurate.
C13	-	The theory must be revised as value from experiment is more accurate/reliable.
C21	-	The experiment has proved that the theory is wrong.
C30	1	Theories are always being improved/refined with new evidence/information.
C31	-	Theories are subject to change with the accumulation of new information.
C40	9	The experiment must be repeated.
C41	15	The theory must be changed if on repeating the experiment (after checking the theory using different/improved conditions/apparatus), the result obtained does not match theory.
C43	3	Repeat the experiment as it involves errors.
C44	2	Repeat the experiment after revising the theory.
C50	2	Theory can never change. It has been proved by earlier experiments.
C60	1	Experiments/measurements have approximations/inaccuracies.
C61	1	Experiments/measurements are affected by external factors(environmental/experimental factors).
C62	-	Measurements/experiments depend on the sensitivity of the apparatus.
C63	-	Measurements/experiments depend on the judgement of scientists.
C70	-	New scientific knowledge can originate from scientific theories only.
C71	-	Previous knowledge in this field has been used to construct the theory.
C80	2	The two values do not have to match.
C81	4	The two values must be the same.
C90	25	Check both the theory and experiment.

14. Finally, you think about how scientists may improve their measurement

N00 - No response

U00 – Not able to code response

	Frequency of codes	
A		With enough money and the best equipment, the scientists can design an experiment that would give them the <u>true value</u> of the magnetic field because...
A00 -	-	(no reason given).
A01 -	21	(not able to code response given).
A10 p	7	the experiment can be refined.
A11 p	2	then the experiment will be successful.
A12 s	10	more accurate results/the correct value can be obtained.
A14 p	1	on repeating the same answer will be obtained.
A20 p	6	only then the exact/required value can be obtained.
A21 p	2	a value closer to the true value can be obtained.
A30 p	30	technology is improving all the time.
A61 p	-	then the reading will have zero uncertainty.
B		That's not true! I think that the scientists will <u>never</u> know the true value of the magnetic field, no matter what they do because...
B00 -	-	(no reason given).
B01 -	3	(not able to code response given).
B12 s	13	more accurate results/the correct value can be obtained.
B13 s	9	only the best approximate/best estimate can be obtained.
B21 p	18	a value closer to the true value can be obtained.
B23 -	3	in physics/science the true result/value cannot be known.
B30 p	1	technology is improving all the time.
B40 p	14	you don't know whether you obtained the true value as you cannot control outside factors.
B41 s	2	there will always be deviation in the results obtained.
B42 s	5	human error or mistakes cannot be avoided.
B43 s	11	measurements/experiments are affected by external/measuring process.
B44 s	14	measurement/apparatus/experiments involve inaccuracies/errors.
B50 s	-	measurement is always quoted as a range/interval.
B60 s	1	it is impossible to get a reading with zero uncertainty.
B70 -	3	science/nature is complex.