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ABSTRACT

This study investigated the effect of two different approaches to practical work on the procedural understanding of foundation level students at two historically similar universities in South Africa, the University of Cape Town (UCT) and the University of the Witwatersrand (Wits), both of which run programs to improve the access of disadvantaged students. Both of these programs feed students into the second year of a three-year science program. A questionnaire probing students' understanding of handling of experimental measures was developed, piloted, and administered to students in both programs before any instruction and after completing their programs. UCT students were exposed to only 5 practical sessions during the school year, while Wits students attended 12 laboratory sessions over the academic year with a practical examination at the end of the year. Both groups made considerable gains during instruction, but, on the whole, the UCT group made less improvement in handling experimental measures. The Wits students, who had more laboratory sessions spread over the whole school year, appeared better able to digest their experiences. Changes in student reasoning are discussed. (Contains 7 tables and 17 references.) (SLD)

The Effect of Instruction on Students' Ideas on Data Handling of Under Prepared Students At Two Historically Advantaged South African Universities

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Introduction

Several attempts have been made to understand the effectiveness of undergraduate chemistry laboratory work in terms of promoting students' understanding of the chemical concepts involved (for instance Miller et al, 1994). Miller et al.(1994) also provide the basis of a growing interest in using laboratory work to develop students' understanding of the methods of scientific enquiry, their so-called procedural understanding, and thus research into the status of students' untutored and learned procedural understanding (see also Allie *et al.* 1998). The status of this understanding amongst under-prepared students in South Africa is of particular interest as these students generally enter university with little or no experience of practical work.

The importance of the topic of data handling has slowly become recognised by those teaching at the tertiary level (Saayman, 1991, Slater and Ryan, 1993; Stubington, 1995 and Metz and Pribyl1995. Hackling and Garnett(1992) compared experts (professional scientists) and novices (year 12 school learners) in their ability to carry out a scientific investigation. Of great interest to this study were the differences found with respect to collection of information on the same task. In contrast to novices, experts reflected on the consistency of results and often repeated measurements when dissatisfied. Only one of the novices repeated a measurement while all the experts in the sample did so as a matter of course.

Millar *et al.* (1994) developed a model where they distinguish three areas of procedural understanding. These areas are students' perceptions of the purpose of doing experimental work, decisions on experimental procedure based on the ability to manipulate apparatus, and finally, their understanding of the reliability of experimental evidence. It is the last of these, which is the focus of the present paper. Lubben and Millar (1996) developed a model of progression of students' ideas concerning experimental data which was later extended by Allie *et al.* (1998) and is shown in table 1.

Table1: A model of progression of ideas concerning experimental data

Level	Student's view of the process of measuring
A	Measuring once and this is the right value
B	Unless you get a value different from what you expect, a measurement is correct
C	Make a few trial measurements for practice, then take the measurement you want
D	Repeat a measurement till you get a recurring value. This is the correct measurement
E	You need to take a mean of different measurements. Slightly vary the conditions to avoid getting the same results
F	Take a mean of several measurements to take care of variations due to imprecise measuring. Quality of the result will be judged only by an authority source
G	Take a mean of several measurements. The spread of all measurements will indicate the quality of the results
H	The consistency of a set of measurements can only be judged and anomalous measurements need to be rejected before taking a mean
I	The consistency of data sets can be judged by comparing the relative positions of their means in conjunction with their spreads

Allie et al. (1999) have taken this model a step further, by characterising the views on data handling above in terms of what they call point and set paradigms. They define these paradigms as follows:

"The **point paradigm** is characterised by the notion that each measurement results in a single, "point-like" value which could in principle be the true value. As a consequence each measurement is independent of the others and the individual measurements are not combined in any way."

"The **set paradigm** is characterised by the notion that each measurement is only an approximation to the true value and that the deviation from the true value is random. As a consequence, a number of measurements are required to form a distribution that clusters around some particular value. The best information regarding the true value is obtained by combining the measurements using theoretical constructs in order to describe the data collectively. The operational tools that are available for this purpose include the formal mathematical procedures that can be used to characterise the set as a whole, such as calculating the mean and the standard deviation. In turn, these quantities become tools for making comparisons with other data-sets or theory."

In terms of these definitions, it can be seen that categories A to D in table 1 above would be part of the point paradigm, while E to I would form part of the set paradigm. Allie et al.'s (2000) study showed that learners do not fall neatly into the two paradigms. In their investigation into the status of procedural understanding of South African foundation physics students, they found that although more than half the students carried out an action that was consistent with a set paradigm, like taking a mean of a set of data, fewer than half of these could provide a reason which was consistent with this action. Hence embracing the set paradigm is a slow process and certainly not achieved in a 12 week laboratory course, even where these concepts are emphasised.

This finding is consistent with the view of learning based on situated cognition (Brown et al., 1989) which considers learning as an integral part of a social practice. Lave and Wenger(1991) see learning beginning as an apprenticeship involving "legitimate peripheral participation" which describes the relationship between newcomers and old timers. The new comers' move from legitimate peripheral participation to full participation describes how they become part of the community of practice. This process subsumes the learning of knowledge and skills. Lave(1997) sums these ideas up as follows:

> *"The idea of apprenticeship, or learning in practice reverses this relation by making central the encompassing significance and meaning - understanding that children have the opportunity to develop* <u>*about*</u> *things they are learning." (p 33)*

Hence all the factors which are aspects of laboratory work, such as declarative knowledge, procedural knowledge and communicative competence are integral parts of participation in a community of practice, in this case, the laboratory. Thus the learner starts as a legitimate peripheral participant with the adoption of routine skills, for example not contaminating solutions, reading burettes at eye level, checking the zero reading on the balance, repeating measurements, using software to construct a line of best fit, or statistical formulae to calculate a mean and standard deviation. He/she then progresses through participation in the social practice of laboratory work to an understanding of the reasons for these procedures. The practices of laboratory work will only have meaning when situated in the practice that generated them. Thus ideas related to procedural understanding need to be experienced by learners in the context where they have meaning. The focus of this paper is to find out if experiences of the learners do indeed generate this learning in context.

British studies on procedural understanding, such as that by Millar *et al.* (1994) have focussed on school students, while South African studies in the area have tended to focus on the university level (Allie et al.1998, Almekinders et al. 1998 and Davidowitz et al. 1999). The study carried out by Allie *et al.* (1998) focussed particularly on students' ability to differentiate between systematic and random errors in experiments. As the study focussed on entering students who were known to have limited experimental experience, it was thought that previous laboratory experience may be a factor in the development of their ideas on experimental data.

The present paper investigates the effect of two different approaches to practical work on the procedural understanding of foundation level students at two historically similar institutions, the University of Cape Town(UCT) and the University of the Witwatersrand (Wits). Both universities run two year programmes to improve access of disadvantaged students. Both programmes feed successful students into the second year of a three year science degree. The UCT programme is known as the General Entry Programme in Science (GEPS), while the Wits programme is known as the College of Science (COS). The procedural understanding of these students on entry was investigated by Rollnick et. al. (1999). Both sets of students were on a special course for underprepared students and had little practical experience at school. They found that the greatest proportion of students displayed point reasoning as defined by Allie et al. (2000) while a much smaller proportion apparently displayed set reasoning. At the time the extent to which this was ad hoc set reasoning was not investigated. A negligible proportion of students had any understanding of spread. The UCT sample had a larger proportion of students opting to take a mean. Higher level responses were found in students who had more laboratory experience.

Aim of the research

This study seeks to answer the following questions:

1. What is the effect of a targeted strategy on the procedural understanding of GEPS students at UCT?
2. What is the effect of the COS programme at Wits on the procedural understanding of the students?
3. What differences exist after instruction between the groups from the two universities?
4. What is the status of procedural understanding of the group as a whole after instruction?

Methodology

A questionnaire probing students' understanding of handling of experimental measurements was developed, piloted and then administered to students entering the GEPS and COS programmes at the two universities before any instruction had taken place, and again after instruction. Procedural understanding is addressed primarily in practical work, but in both groups, concepts associated with experimental procedures were also dealt with, implicitly or explicitly, during tutorial sessions.

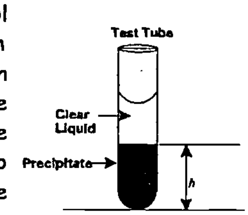
The UCT students were exposed to only 5 fortnightly practical sessions during the entire year, and these were all concentrated in the first semester. All five experiments involved measurement, three of them asking for repeat readings (two titrations and a gravimetric analysis) and one required the drawing of a straight line graph. One experiment also asked students to determine a mean and standard deviation, but neither of these concepts was explained, students were merely meant to calculate the figures using a given formula.. As this was the only practical experience the students were to have for the year, many of the experiments were based on theory that they may have been exposed to at school but had not yet covered during their lectures at university. The researchers had no control over the experiments offered to the class, but were given the chance to hold five "dry laboratory" sessions in the weeks between the practical sessions. These sessions aimed to address some of the conceptual background and also procedural aspects connected to the coming practical session. The classes took the form of a large group tutorial where students sat in predetermined groups and worked on tasks given to them. At the end of the session groups reported back in plenary fashion. Each group was required to submit written answers which were marked and returned to the group.

The Wits students attend 12 fortnightly laboratory sessions spread over the academic year, and are required to take a practical examination at the end of the year. They also attend small group tutorials twice weekly. The focus of these tutorials is primarily on the theoretical, or declarative understanding of the students, but some of the early tutorials address issues like precision and accuracy, and significant figures through reading from diagrams of burettes and measuring cylinders. There is no explicit mention of either mean of standard deviation in either these classes or the practical sessions. Most experiments involve taking measurements, but only a few explicitly require repetition of readings, most notably on the titration experiment. This is due to the fact that many chemistry procedures are lengthy and a three hour afternoon practical does not allow for several runs of one experiment. However, demonstrators frequently pool results for their group of 20 students and multiple readings are obtained in this way. Students are asked to draw straight line graphs on at least three occasions. The demonstrators are mostly graduate students who are trained in a one day training course at the beginning of the year and receive short briefings at a pre laboratory meeting with the laboratory manager.

The questionnaire consisted of nine tasks, all based on the same experimental situation. The situation presented to the students in the questionnaire is shown in fig. 1 below:

Fig. 1: Situation presented to the students

Some students are doing an experiment in the chemistry laboratory. They have a flask with a 1 mol dm^{-3} solution of lead nitrate ($Pb(NO_3)_2$) and another flask with a 1 mol dm^{-3} solution of potassium iodide (KI). The students pour 5 ml of lead nitrate into a test tube. When potassium iodide solution is added to the lead nitrate solution, they see a yellow precipitate. They put a cork on the test tube and leave it to stand for 4 hours. The yellow precipitate has settled to the bottom of the test tube and a clear liquid remains on top as shown in the diagram. The students have been asked to investigate what happens to the height of the precipitate (*h*) when the volume of potassium iodide solution(*V*) is varied. They use a ruler to measure the height *h* in mm.



A completed version of the experiment was shown to the students. The rest of the questionnaire contained questions based on this experiment, where cartoon characters were used to represent the experimenters and their different points of view. For example the first question (RD) is shown in fig. 2 below.

Fig. 2 Example of First Question (RD)

The students work in groups on their experiment. Their first task is to find *h* when *V* = 5ml. One member of the group adds 5 ml of the potassium iodide solution to the 5 ml of lead nitrate and measures the height of precipitate using a ruler. They measure *h* to be 11 mm. The following discussion takes place between the students.

A. I think we should do the experiment a few more times with the same volume of potassium iodide solution and measure *h* each time

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

C. I think we should do the experiment just one more time with the same volume of potassium iodide solution.

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

Explain your choice.

Each question was printed on a loose, separate page. Students were required to answer each question and immediately insert it into an envelope, so that they did not return to earlier questions. The pre-test questionnaires were coded using alpha numeric codes and analysed in terms of the models of Lubben and Millar(1996) and Allie et al.(1998). This analysis was then modified using the point and set paradigms as defined by Allie et al. (2000). The groups were then exposed to instruction. The pre-test questionnaire was modified by including two extra questions on spread and administered to both groups as a post test. The UCT students answered theirs at the end of the first semester while the Wits students answered theirs at the end of the academic year (two semesters). The UCT students did no laboratory work in the second semester, so the post test also marked the end of their practical course.

Findings:

All in all, seven tasks were analysed in the pre-test and nine in the post test. Only students who answered both the pre-test and the post -test were subjected to analysis. 73 UCT Students and 124 Wits students answered both tests.

Perceptions about reasons for repeating measurements

The first two questions addressed the issue of the reasons for repeating measurements. In the first question (RD, see detailed question above) students explained if and why they thought repeating measurements was required after taking one reading, and the second question (RDA) raised the same issue but after two different readings. The third question (UR) presented them with a set of five measurements which they were to represent with one number, the height of the precipitate. Two of the five measurements were identical numbers.

In analysing similar tasks in physics, Allie et al.(2000) warns that students calling for a mean to be generated may falsely give the impression of set reasoning, as their reasons may not be to take account of the spread of that data. In spite of this, it was even possible at this stage to pick out ad hoc, or algorithmic set reasoners. These were students who displayed point reasoning on the first two questions (see examples below) and then used set reasoning by calculating a mean when faced with five readings. In this study this mixed usage of paradigms is coded as category R.

In our analysis we also felt the need to distinguish between two levels of point reasoning as two distinct groups of students could be distinguished at this level, particularly on the pre test. The first (category P) level comprises levels A-C of the earlier hierarchy developed by Allie et al.(1998), where students essentially believe that only a single reading should be taken, though perhaps some practice is necessary before this reading is taken. So learners in this category could be described as "non-repeaters and believers in practice". Typical responses in this category would be

> *"Because the experimental results cannot be the same and the more doing the experiment the more you become a little bit accurate to get the conclusion of final measurement. They will have the correct answer"* (447 - UCT student)

> *"I don't think they need to repeat the experiment again because repeating the experiment with the same volume of KI will only give us the same height again"* (457 - UCT student)

The second level(category Q) would consist of those students who believe that multiple readings should be taken, but for the purpose of confirming the first reading. Only similar readings are correct. For example,

> *"I think it is best for one to make an experiment for few times, because one needs to have the exact measurements. If you do it three times and still have the same result it will mean that you have the correct answer"* (293 - Wits student)

A student adhering to the set paradigm would provide responses like the one below:

> *"The final result of one experiment may vary from others. By doing a few more experiments, the students can get an average and this should be more closer to the correct answer"* (215 - Wits student)

Table 2 below shows summaries of the responses given by the Wits and UCT Students to these first three questions.

Table 2 Reason for doing repeats: Responses to RD, RDA and UR tasks (Pre and Post test)

Code	Description	UCT % (n=73)		WITS % (n=124)	
		Pre	**Post**	**Pre**	**Post**
P	Point Paradigm 1: Non-repeaters and believers in practice	8	0	6	0
Q	Point Paradigm 2:Believe in Recurring Readings	41	23	59	14
R	Mixed Paradigm:Basic belief in recurring reading, algorithmic mean taker	14	16	13	14
S	Set Paradigm: Mean takers	34	60	15	70
U	Unclassifiable	3	0	7	2
Total		100	100	100	100

The figures in the table show that there has been a considerable change of views during the process of instruction. The students adhering to point paradigm 1(P) have disappeared from the sample. The biggest change, however was from point paradigm to set paradigm. This change has been most marked in the case of the Wits sample which initially had a much smaller proportion of set reasoners.

The Wits sample seems to show the greatest movement, staring with a higher proportion of point reasoners, but ending with a higher proportion of set reasoners.

The same classification system (P to S) was used to track the individual changes in the whole group and is shown in table 3 below.

Table 3: Shifts in responses to RD, RDA and UR tasks of the entire sample (n=197).

	P pre	**Q pre**	**R pre**	**S pre**	**U pre**	**Total Pre**
P post	0%	0%	0%	0%	0%	0%
Q post	0%	15%	0%	0%	2%	17%
R post	2%	5%	5%	2%	1%	15%
S post	5%	31%	8%	20%	2%	66%
U post	0%	1%	0%	0%	1%	2%
Total Post	7%	52%	13%	22%	6%	100%

The shaded area on the table shows where the beliefs about repeating has stayed the same or advanced. The largest shifts (over 30%) can be seen from point to set paradigm (from P and Q to S), while 20% retained their belief in repeating to take a mean (S to S). The cells above the shaded area, which represent a regression contain low percentages of students indicating few relapses from the use of set to point paradigm.

The Significance of Spread

Three further questions explored students' ideas about the significance of spread in a set of repeated measurements. The first question (AN) presented six readings (15, 11, 24, 10, 11 and 13 mm) and asked students, if and why, in calculating the mean the value of 24 mm needs to be discarded. The next question (SMDS) presented two sets of measured precipitate heights with identical means (12mm) but different spreads. Students were asked if and why the different spreads influenced the quality of both sets of measurements. A last question (DMSS) provided two sets of measurements with a different mean (12mm and 14mm respectively) but the same spread, and students were asked if and why these sets of information represented the same or different results. Table 4 presents the clustered responses to these three questions for the two groups before and after instruction.

Table 4: Judgement of similarity of data sets: Responses to AN, SMDS and DMSS tasks

Code	Description	UCT % (n=73)		WITS % (n=124)	
		Pre	Post	Pre	Post
V	Point paradigm 1: Compare individual measurements	16	10	9	4
W	Mixed Point Paradigm:Compare only the mean, take no account of spread, anomaly seen as a mistake	48	29	42	23
X	Limited Set paradigm: Compare means, and only if they are the same, consider spread	29	36	44	59
Y	Set Paradigm:Only spread is important, mean is not mentioned	4	8	3	4
Z	Advanced Set paradigm: Consider mean, spread and overlapping spread as important	0	5	1	4
U	Unclassifiable	3	12	1	6
Total		100	100	100	100

Again the responses of the students showed a development from point to set paradigm showing various stages of sophistication. W, as characterised by Allie et al. (2000) shows the existence of ad hoc set reasoning. Students in this category seem to regard the mean as an "answer" or a "result" rather than a measure of central tendency . They also regard anomalies as "mistakes". Students in category X are able to consider the spread of two sets of data provided the means are the same, but are thrown if the means are not the same, while those in category Y consider spread only irrespective of the mean. Only those in category Z take account of mean, spread and overlapping spread as important.

In both groups only a small minority of students both in the pre test and the post test consider spread when the means differ (Z), though a higher proportion of UCT students place considerable emphasis on spread in the post test (Y+Z). Another notable feature of the UCT group is the large proportion of unclassifiables (12%) in the post test. What emerges is that, apart from the 8% of UCT students in category Y, a large proportion of the UCT students end up either confused (U) or taking no account of spread (V+W). However, nearly 60% of Wits students seem to take a limited view of spread. Only just over a third of UCT students reach this stage.

The individual shifts from pre to post test for the whole group are shown below in table 5.

Table 5: Shifts in responses to AN, SMDS and DMSS tasks of the entire sample (n=197)

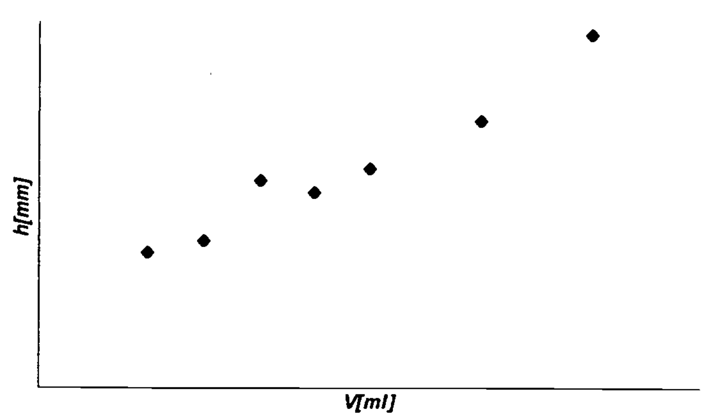
	V pre	W pre	X pre	Y pre	Z pre	U pre	Tot post
V post	1%	3%	2%	0%	0%	0%	6%
W post	2%	14%	8%	1%	0%	1%	25%
X post	5%	20%	22%	2%	0%	0%	49%
Y post	1%	2%	1%	1%	0%	0%	5%
Z post	1%	2%	2%	1%	0%	0%	6%
U post	1%	4%	3%	1%	0%	0%	9%
Pre tot	11%	45%	38%	5%	0%	1%	100%

Again the shaded cells in the table show where understandings have remained constant or have improved. Again the unshaded cells above these cells show very small percentages (all below 10%) showing in general positive changes after instruction. Nevertheless, only a small proportion of students end up in categories Y and Z, showing that the appreciation of spread is limited to cases where the means of two sets of readings are the same (X).

Students' Ideas about Data processing

One of the questions (SLG) required students to fit a best straight line to data provided for different volumes of lead nitrate added to the solution. The students were provided with a graph showing a set of points as shown below in Fig. 3.

A group of students measure h for different volumes of potassium iodide solution and plot them on a graph as shown below. On this graph, draw the straight line that you think best fits this data.



Explain what you have done and why.

Fig. 3: The Straight line task (SLG)

Students responses in this task were compared to their responses on the UR task, described above. The UR task requires students to provide a numerical result from 5 readings. There appears to be a strong link between the thinking behind the two tasks, both requiring students to process data. Apparent conflicts between set and point reasoning become very clear when comparing these two tasks. Table 6 presents the clustered responses to these two questions for the two groups before and after instruction.

Table 6: Comparison of UR and SLG tasks

		UCT (n=73)		WITS (n=124)	
Code	**Description**	**Pretest**	**Post test**	**Pretest**	**Post test**
Q	Point Paradigm 1	15%	5%	22%	4%
S	Point Paradigm 2	23%	16%	35%	15%
R	Mixed Paradigm	42%	48%	23%	59%
T	Set Paradigm	7%	19%	7%	18%
U	Unclassified	12%	11%	13%	5%
Total		100%	100%	100%	100%

Responses to the SLG task were of three main types - students drawing broken lines connecting the points, students drawing a straight line through selected points and students drawing a "best fit" straight line. Only the last category displays set paradigm reasoning. Some typical responses to this task are shown below:

> *"They needed to join the lines according to the arrangement of all dots because the plot the dots according to the data given"* (260 - Wits Student, broken line)
>
> *The line that goes through most of the points give a precise answer. The points which are not the line might be readings that are caused by error in readings.* (223, Wits student line through selected points)
>
> *The line best represents the trends as volume increase what height would do since the points are sightly scattered on average line/best fit line would best fit the relationship between V and h.*(224 - Wits student, line of best fit)

These points of view relate closely to the UR responses where learners either suggest responses suggesting choosing individual points based on their position in the set (point paradigm 1), because the readings recur (point paradigm 2) or choosing a value which corresponds to the calculated mean (point paradigm).

Table 6 shows that a consideration of these tasks indeed separates set reasoners from those who are using the mean concept algorithmically. Again we have found it useful to separate the two levels of set reasoners as in the first three questions. The proportion of set reasoners emerging from both groups is not very different, but the Wits group contains a far higher proportion of point reasoners to begin with. As with the other tasks, the shift in the case of the Wits group is much higher. Nevertheless it is clear that by the end of the intervention, more than half the Wits learners and almost half the UCT learners show the same tendency as the group studied in Allie at al.(2000), towards set action but point reasoning. Just under one fifth emerge as set reasoners, compared to 23% in Allie et al.(2000).

The shifts for the group as a whole is shown in Table 7.

Table 7: Shifts in responses to UR and SLG tasks

	Q pre	S pre	R pre	T pre	U pre	Total
Q post	1%	2%	1%	0%	1%	5%
S post	5%	7%	2%	0%	2%	15%
R post	10%	17%	17%	5%	7%	55%
T post	3%	3%	8%	3%	3%	18%
U post	1%	5%	1%	0%	2%	7%
Total	19%	32%	28%	7%	13%	100%

Table 7 shows that the shift to mixed paradigm reasoning is from both types of point reasoning. The largest shift to set reasoning (8%) comes from mixed paradigm reasoning, but it is not large enough to draw the conclusion that the mixed reasoning may be a stepping stone to point reasoning.

Discussion and Conclusion

Both groups made considerable gains during instruction, a great proportion of both groups moving to repeating for the purpose of taking a mean and taking account of spread when comparing two data sets only when the means are equal. However important differences emerge between the groups. On the whole, the UCT group made considerably less improvement in all sets of data analysed above. However, a small percentage of this group showed considerably more progress in understanding spread. On the other hand, the UCT group had a much higher proportion of unclassifiable cases. These differences are not unexpected given that the two groups had completely different teaching. The UCT group experienced only five laboratory sessions, but received a targeted intervention before each laboratory which included an explicit introduction to standard deviation. The Wits group were not taught the concept at all.

The Wits students experienced twice as many laboratory sessions as the UCT students. Their demonstrators were trained in both demonstration and marking of laboratory work. Weekly pooling of results allowed students to see the benefit of having many readings albeit from different sources. On the other hand, thy received no targeted instruction on the concepts explored in the questionnaire used in this study, apart from a few tutorials on the topic of significant figures and .precision and accuracy. The UCT students worked with three specially designed exercises targeting the relevant aspects of procedural understanding. They were introduced to the concepts of spread, standard deviation, means and did an exercise on fitting a straight line to a set of points.

It appears that the intensive nature of the practical experience left many of the UCT students confused, while a few of the more able students were able to gain quite a sophisticated understanding of spread. The Wits students, on the other hand, were able to digest their experience over the whole year and ended up with an intuitive, though limited understanding of spread. The profile of their results closely resembles that obtained by Davidowitz et al. (1999) with beginning second year students. In the case of the UCT students, the concept of spread was introduced as immediate preparation for a specific practical session without later reinforcement thus precluding students from generalising their procedural understanding. It seems that the introduction of the formal idea of spread, including the accompanying algorithms, before an intuitive understanding of the concept of variability of measurements has little effect, or causes mainly confusion.

The group as a whole appeared to move from largely using a point paradigm to mixed paradigm reasoning involving ad hoc approaches such as algorithmic mean taking. As in the study by Allie et al.(2000) only a fifth of the students emerged as set reasoners. Table 7 shows that of the few who move to set reasoning, a larger proportion began the intervention using a mixed paradigm.. This finding is surprising as alternative conceptions research (Scott et al., 1994) shows that learners using both alternative and scientific conceptions are the most difficult to shift to a consistent use of scientific conceptions.

The point and set paradigm classification seems to yield similar results to the study carried out by Allie et al.(2000). The classification of responses as signifying either a point and set paradigm seems to be a useful way to characterise student thinking on this issue. However, a successful approach to teaching ideas about reliability of data needs to go beyond this. Seeing multiple readings as a set of data rather than separate points requires extensive participation in the social practice which is laboratory work. Students need to make the move from that of legitimate peripheral participant (Lave and Wenger 1991) to full membership of chemistry laboratory practice.

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