B. Davidowitz, M. Rollnick and C. Fakudze,
S. Afr. J. Chem., 2003, **56**, 47–53,
<http://journals.sabinet.co.za/sajchem/>.

Increasing the Signal to Noise Ratio in a Chemistry Laboratory – Improving a Practical for Academic Development Students

Bette Davidowitz[a*], Marissa Rollnick[b] and Cynthia Fakudze[c]

[a] *Department of Chemistry, University of Cape Town, Rondebosch, 7701 South Africa.*

[b] *College of Science, University of the Witwatersrand, Johannesburg, 2050 South Africa.*

[c] *Department of Biodiversity and Conservation Biology, University of Western Cape, Bellville, 7535 South Africa.*

Received 10 July 2002; accepted 23 June 2003.

ABSTRACT

In practical sessions students lack sufficient time or opportunity for deep processing of information. If the signal to noise ratio is too low, it can obscure the 'chemical message' which the lecturer is trying to convey. This study reports on an action research driven attempt to improve on a Hess's Law experiment, well known in most first year curricula. Data collected in 2000 indicated that students struggled primarily because there were too many practical demands to allow them to focus on the concepts involved. The exercise was thus divided into two sessions in 2001, the first to address the issues related to techniques required, the second, similar to the experiment in 2000. Analysis of data collected in 2001 shows that the changes made a significant impact on the effectiveness of the laboratory session.

KEYWORDS

Chemical education, action research, curriculum design, laboratory exercises.

1. Introduction

Novices in the laboratory are similar to learner drivers who are concentrating on mastering the controls of a car and do not manage to observe the road outside. Students are expected to acquire practical skills and procedural understanding[1] while at the same time learning chemical concepts. Interaction with undergraduates over many years has revealed that most students view practicals as an exercise in task completion[2] and do not learn much in the way of concepts.

Roth *et al.* have shown that in observing the same experiments, students (novices) and teachers (experts) do not necessarily make the same observations.[3] There are two possible reasons for this. The first may be due to the difference in theoretical backgrounds between the teachers and students. The second could be attributed to the different levels of competence in carrying out experiments.

This paper presents an action research study of the improvement of an exercise on Hess's Law designed for academic development students at the University of Cape Town. These students are generally from disadvantaged backgrounds and are given two years to complete the equivalent of the first year chemistry course. This work is part of a larger study aimed at lowering the cognitive load on students and focuses on a laboratory session which presented a number of problems when it was first offered.

2. Background

In traditional chemistry laboratories, students do not find time to carry out deep processing of information.[4] Part of the difficulty is alluded to by Johnstone who presents an information processing model which shows how students are limited by the amount of information they can process at one time.[5] Furthermore what students process is acted on by what he calls a perception filter which is influenced by students' existing schema i.e. cognitive structures that exist in their minds. In an earlier paper Johnstone talks about the importance of signal to noise ratio in determining how much information a student is able to process in an experiment where there is a mass of extraneous information.[6]

Johnstone and Wham describe class teaching as a process beginning with a single idea which is elaborated.[7] Practical work on the other hand, tends to start with a number of different observations representing a set of disparate ideas from which the student needs to draw a single relevant one. Related to this is the well-known critique of inductivist theory restated by Roth *et al.* concerning the theory-laden nature of observation.[3] Students thus need to enter the laboratory in possession of the prerequisite theory in order to extract maximum benefit from the practical.

In view of this, it would make sense to redesign particular experiments by stating clearly the objectives of the experiments as well as paying particular attention to the way in which the instructions are presented in the laboratory manual. This may eliminate the noise which is overloading the students.

Rollnick *et al.* proposed a refined information processing model which conceptualizes a student engaging in a decision-making cycle involving stages of selection, reflection and organization of ideas as shown in Fig. 1.[8]

This decision-making cycle is influenced by various factors impinging on laboratory experience, such as declarative knowledge, procedural knowledge and communicative competence, all linked by the social interactions necessary to internalize them.

Declarative knowledge is characterized as conceptual structures relating to the subject matter content that the student has prior to, and after doing the laboratory work. These conceptual

* To whom correspondence should be addressed: E-mail: bette@science.uct.ac.za

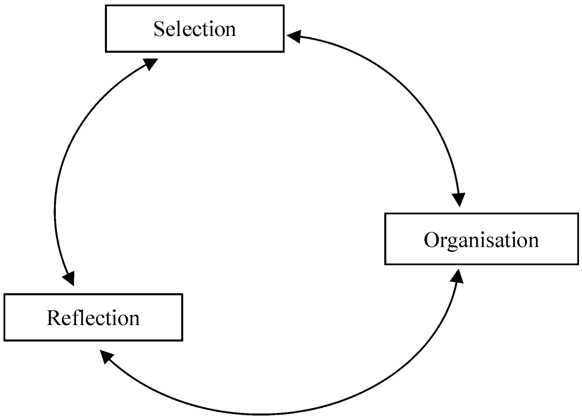

Figure 1 Information-processing model.

structures influence the ability to process any content-related information which arises in the laboratory. Procedural knowledge refers to the conceptual structures relating to the methods of scientific experiments that the student has prior to, and after doing laboratory work. Procedural knowledge encompasses comprehension of the purposes of experimental procedures, an ability to assess the plausibility of data collected, the ability to make sensible predictions of experimental results and the ability to carry out a critical analysis of sources of error in the experiment. Communicative competence rests on the premise that language is not merely a set of grammatical structures but a system of communication. It is thus a broader issue than just reading and writing; it encompasses an understanding of when and how to use scientific language.

As in Johnstone's model the interaction of these factors with the decision-making cycle (Fig. 1) would be affected by inputs in the form of a task and result in outputs, for example in the form of a laboratory report. This is shown in Fig. 2.

Figure 2 illustrates the case where the student has been presented with a laboratory experience, has gathered data and has to produce a report. In Johnstone's terms the signal would relate to the expected output in the form of a report while the noise may be caused by extraneous issues which are associated with factors impinging on the decision-making cycle as shown in Fig. 2.[6] If the signal to noise ratio is low, then the student will have difficulty in selection of relevant ideas, resulting in a disruption of the decision-making cycle and consequent difficulty in calling on resources, such as relevant conceptual and procedural understanding needed to tackle the laboratory exercise. This disruption would also impact on the output which in this case is the laboratory report.

This project is aimed at improving the laboratory experience for students by reducing noise to allow opportunities for deep processing of information.[9] The only way to achieve understanding is to apply a deep-learning approach in which the student focuses on the concepts learned in lectures and relates them to the practical course. The student is able to interpret data and write a coherent practical report. A student who engages with the material feels a sense of achievement and satisfaction from understanding the task at hand. By contrast, a student adopting a surface-learning approach, will focus on task completion and will not reflect on the concepts. Learning outcomes also depend on the approach taken by the student. Better quality outcomes and higher marks are related to deep approaches to learning.

There are often problems with the articulation of the teaching of content and the practical work based on the content. Even though overt links are sometimes made, students frequently are not able to link the laboratory activities with the material covered in lectures.[10] Therefore the study of students' experiences of the laboratories should be linked to the improvement of those experiences by refining the design of the practical sessions.

3. Aim of the Research

The primary aim of this research was to track a single experiment over a period of two years using the technique of action research to:

- Evaluate a laboratory exercise to illustrate Hess's Law.
- Investigate the effect of improvements implemented as a result of the evaluation.

4. Participants in the Research

The students participating in this research were enrolled on an academic development course and generally had little or no

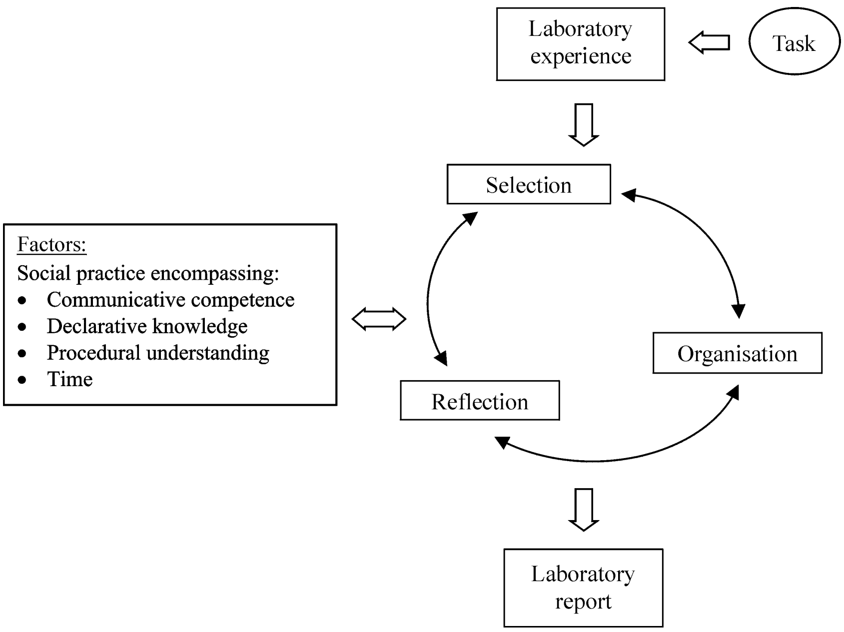

Figure 2 Interaction of factors with decision-making cycle.

experience of carrying out experiments. Global data was collected for 160 students in 2000 and 125 in 2001, while a close study was made of a subset of 13 students in 2000 and 14 students in 2001. The subset of students in both years were those in the group supervised by a teaching assistant acting as a participant observer.

5. Methodology and Analysis

This study adopted an action research methodology[11] on a well-known class experiment to verify Hess's law which had been in use with the mainstream first year classes for some time.[12,13] This is a traditional quantitative experiment which aims to illustrate an important chemical law and introduce students to careful quantitative work and the use of associated apparatus. According to Hess's law of heat summation, the enthalpy change of a process is the sum of the enthalpy changes of the individual steps. In many cases it is not possible to measure the enthalpy change for a particular reaction directly. In applying Hess's Law, a reaction is imagined as the sum of a series of steps for which the enthalpy changes, ΔH, are known. As the overall enthalpy change only depends on the initial and final states for the reaction, the known ΔH values are added together to obtain ΔH for the reaction.

In the design of this and other experiments in the course, careful attention was paid in both 2000 and 2001 to pre-laboratory preparation and clarity in the writing of the practical manual. Each group of 16 students in the class was under the supervision of a trained demonstrator who managed both pre- and post-laboratory discussions as well as close supervision of students as they worked. The post-laboratory discussions were characterized by a pooling of group results and drawing of conclusions from the experiment.

Data for this research were collected as students carried out experiments on the topic of Hess's Law during 2000 and 2001. In 2000 the demonstrator of one group in the laboratory acted as a participant observer and kept detailed journal notes of events taking place during the laboratory exercise. In addition, her group's participation in the session was videotaped. Students' laboratory reports were also photocopied for the group under focus.

Analysis of the 2000 data indicated that the students struggled with the practical primarily because the signal to noise ratio was too low – there were too many new demands in the laboratory itself, such as using an unfamiliar mechanical balance, to allow the chemical 'message' of the practical to emerge.

As a result, the exercise in 2001 was divided into two sections – the first, experiment 4a, to address the issues related to the techniques and basic concepts required. The second, experiment 4b, was identical to the 2000 version of Hess's Law with some minor alterations, most notably asking for only one set of readings and pooling results at the end of the session. Another major change to the 2001 experiment was the introduction of electronic top loading balances instead of mechanical balances and flexible weighing boats in the place of watch glasses. Similar data to that of 2000 was collected in 2001. In addition interviews were held with selected students in 2001 as well as with demonstrators who had been present at both the 2000 and 2001 laboratory sessions. An additional written question was also presented to the students in 2001 asking what they thought they had learned from the experiment.

6. Findings

Analysis of the data revealed that there were several important differences between the practical on Hess's Law in 2000 and 2001. These are discussed below. It should be noted that in both years students were well-prepared for the laboratory exercises. They had all completed a flow diagram[14] for each experiment and had attempted to answer the pre-laboratory questions.

A summary of the findings is given in Table 2.

6.1. Pre-laboratory Discussion

The focus of the pre-laboratory discussion in 2000 was mainly on procedural issues such as use of the apparatus. Video evidence showed that students were alerted to the hygroscopic nature of the sodium hydroxide. The demonstrator stressed the need to weigh the solid quickly so that it did not pick up moisture. Students were shown the location of the mechanical top-loading balances which they had not used before. The scale on the thermometer was also highlighted. There was a brief mention of Hess's Law and a reminder that it was a topic that had been covered during lectures. Safety issues were also addressed as well as the need to do the experiment twice and to take an average. Students asked few questions even though they were invited to do so.

In 2001 the pre-laboratory discussion was far longer and focused almost entirely on conceptual issues. Beginning by overtly linking the experiment to theory covered in lectures, the demonstrator explained how to use the density of the solution to calculate the mass and wrote the relevant equations on the blackboard. She engaged students in a fairly detailed discussion on how to do the calculations as well as the pre-laboratory question which required the students to calculate ΔH for one of the reactions in the experiment. There were 12 student inputs during this time, most of them in response to questions posed by the demonstrator but 3 inputs were initiated by the students themselves. One of these concerned a pre-laboratory question on using literature values to calculate the enthalpy change for the reaction of an aqueous solution of HCl with an aqueous solution of NaOH. An excerpt from the video follows:

Student No. 60: 'There were no values given for aqueous solutions of NaCl in the textbook.'

Student No. 69: 'You can use the values for Na^+ (aq) and Cl^- (aq).'

[Student No. 62 agreed with him. The demonstrator then explained that an aqueous solution of NaCl contains both Na^+ (aq) and Cl^- (aq).]

Student No. 60: 'So you add them?'

Student No. 69: 'Ja, you add them together.'

6.2. The Laboratory Session

The actual laboratory session in 2000 was dominated by difficulties with the use of the balance. Students struggled to use the antiquated mechanical top-loading balance which they had not used before. The demonstrator, a former school teacher in her early forties said at one stage:

'These are old-fashioned balances, I used one when I was a student.' (Video, 2000).

The demonstrator was recorded on 11 separate occasions helping different groups of students with the balance. The video footage reveals a discussion during which the demonstrator actually shows another demonstrator how to use the balance. Students struggled with the concept that in order to find the mass of the solid, they had to weigh the watch glass, record the mass, add the sodium hydroxide, record the mass and subtract the two readings. This is in line with Johnstone and Wham who note that when students experience problems with manipulative skills, these can seriously hamper the acquisition of other skills.[7] The students' lack of laboratory experience becomes particularly evident when attempting to find the mass of a solid. Tertiary level instructions often take for granted the understanding involved in subtracting the mass of an empty container from a total mass or taring the balance. One incident, recorded in the video in 2000, illustrates a student with this problem. Student No. 135, has just asked the demonstrator how to obtain the mass of a solid.

> Demonstrator: 'You cannot touch the little pellets by hand.'
>
> Student No. 135: 'Ohhhhh'. [Eyes suddenly light up with understanding.]
>
> Demonstrator: 'You need a container to put them in. You can't put them directly on the top of the balance because you will damage the metal.'
>
> Student No. 135: 'So you mean I will first measure the watch glass, then I will measure the watch-glass plus the pellets, then I will subtract the mass of the pellets?'
>
> [The demonstrator nods in agreement and the student smiles and 'high fives' the demonstrator to show his excitement at having grasped this concept.]

In another incident two groups of students struggled to read the calibrations on a thermometer calibrated to 0.2°C. There were several questions about the calculation of the mass of the solution, required later in the calculation of ΔH. Other questions included the calculation of ΔT, conversion of mass to moles and actual calculations of ΔH. Students worked in pairs and each student carried out the experiment, thus each pair had two sets of readings. There was a sense of haste as the students rushed to finish.

By contrast, the students in 2001 required no assistance with the use of the thermometer as they had used it the previous week. The newly acquired top loading balance also presented little problem. In fact, several of the students discovered that they could tare the balance with the weighing boat in place. This simplified the weighing procedure and speeded up the whole process. There were no questions about the use of the thermometer. Students worked in pairs to carry out the experiment and the actual practical was completed in about 60 minutes. There were a few questions related to ΔT, conversion of mass to moles and the actual calculation of ΔH but most students seemed to cope easily.

Instead of focusing on the use of the balance, students' questions were centred on conceptual issues such as the use of the density of water to calculate the mass of the dilute solutions, a concept which still remains a problem for students at this level. However, this was important evidence that students were engaging with issues related to signal rather than noise.

The following quotation recorded during an interview between the first author and one of the demonstrators (BJ) who had been part of the team in both 2000 and 2001 illustrates the contrast between the two sessions.

> 'This year I didn't have to explain it [the use of the balances] all again for this prac (Hess's Law) because they used it in the previous prac (4a). So nobody asked me anything about the balances'. (Interview, demi BJ).

Another demonstrator involved in 2000 and 2001 commented about the balances:

> 'This year (2001) we were lucky to be able to get the easy ones [referring to the electronic balances] which we went to work with. I gave them only one demonstration about how the balance works and that was it. Then they just did their work.' (Interview, demi EW).

6.3. The Post-laboratory Discussion

The post-laboratory session in 2000 was very rushed, a few students wrote their results on the blackboard but there was no discussion or comparison of results within the group.

By contrast, the session in 2001 lasted about 20 minutes. Seven sets of results were written on a pre-prepared A3 sheet. Students were asked to record ΔT and ΔH for each of the three reactions and except for one result which later turned out to be an error in a calculation, the agreement was very good. There was an opportunity to link the results obtained to Hess's Law and to discuss the concept of a state function. Students were able to pick out anomalous results and discuss possible reasons for the anomalies. They also compared their individual results with the average calculated for the group and noted that the results were precise. At the end of the discussion the demonstrator asked whether the students were happy with their sign of ΔH (results were all written as positive numbers). The students then realized that they should have recorded ΔH as being negative as the temperature of the solutions had increased in all cases. One of the students said:

> 'Heat was evolved during the reaction'. (Video, student No. 67, 2001).

There was also an opportunity to discuss a post-laboratory question on internal energy as well as aspects of the laboratory report. At the end of the session students did not rush home but sat on the desks and chatted to the demonstrator about future chemistry courses.

6.4. Laboratory Reports

Analysis of the laboratory reports of the 2000 cohort revealed that the results for the group were inaccurate. Despite the fact that the students had worked in pairs, only about half of them reported both sets of results and very few of them reported the results for the group. The main idea of the experiment, namely calculation of the enthalpy change, was often not mentioned.

In 2001, each student reported the results for the whole group as these had been recorded during the post-laboratory discussion. The results were both accurate and precise. The students were able to discuss procedural issues such as the need to repeat experiments more than once, the precision of the results and the possible sources of error. Despite the fact that most students could identify the anomalous reading during the post-laboratory session, only a few of them referred to it in their laboratory report. Perhaps this was due to the fact that students would have followed the guidelines for writing a report in the practical manual and there is no mention of the need to comment on anomalies. Thus, the extra time during the practical session allowed students an opportunity to reflect on procedural issues. These have a close relationship to the understanding of the nature of science.

The researchers rated the students' reports in terms of their conceptual and procedural understanding as well as communicative skills using a set of predetermined criteria. The rating process was peer validated. A comparison of the average values as well as the maximum score is shown in Table 1.

Although a Kolmogorov-Smirnov test[15] revealed that there was no significant difference in the ratings for the two cohorts of

Table 1 Comparison of average of ratings for laboratory reports between 2000 and 2001.

	Average for 2000 $n = 13$	Average for 2001 $n = 14$	Maximum score
Declarative knowledge	5.5	6.0	10
Procedural understanding	3.2	3.4	5
Communicative competence	3.7	4.5	6

students, the researchers noted that the reports for the 2001 group were more coherent. Coherence refers to how the parts of the report are linked together, e.g. if the students report a mass of a particular substance in the results section, do they make use of this in their discussion. The results obtained by the 2001 cohort were both more accurate and precise than those for the 2000 group. This suggests that the students in 2001 were able to focus on the task in hand without having to cope with the demands of using the apparatus. For both cohorts, the conceptual demands were high, very few of them were able to answer a post-laboratory question on internal energy. Thus, while practical sessions may be an opportunity to link the theory to the experiment, students will not necessarily learn new concepts unless overt links are made such as references to the text book.

In a questionnaire administered at the end of the of the practical on Hess's Law in 2001, students were asked 'what was the most important thing that you learned from this practical?' A clustering of the class's responses to this question shows that an overwhelming 50% of answers given focused on links between theory and experiment. The next highest category of response was related to the use of equipment and procedural understanding (15%). Typical responses included:

> 'I have learned that by applying the knowledge acquired in lectures and tutorial sessions we can successfully carry out the experiment, thus producing reasonable results.' (Questionnaire, student No. 65).

> 'I have learned how to use lab equipment like the thermometer, balances and glassware etc.' (Questionnaire, student No. 53).

7. Reflection on the Observations

The experiment in 2000 was viewed as having too low a signal to noise ratio and several changes were implemented in 2001. The 2001 practical manual was edited for clarification of procedures and questions. In particular, one of the pre-laboratory questions was also modified in an attempt to clarify the concept.

The 2000 experience with antiquated balances motivated the purchase of new electronic balances in 2001. These simplified the weighing procedure. In the words of one demonstrator who was present in both 2000 and 2001:

> 'In 2000 there was a huge bottleneck with the weighing, demis were pre-occupied getting weighing right, no time to deal with other matters. The new balances took away a lot of the hassle'. (Interview, demi AT).

Another facilitating factor in 2001 was the use of weighing boats instead of watch glasses. As these boats are flexible, they were much easier to use and the sodium hydroxide could be added easily to the solutions in the calorimeter. The balances could be tared with the weighing boats in place, requiring only one reading for the mass of the sodium hydroxide.

In 2001 the post-laboratory discussion was made easier by the use of A3 sheets which were provided for the demonstrators to encourage students to pool their results and provide a starting point for post-laboratory discussion. It turned out that in one of the groups where the demonstrator did not use this sheet, many students made a mistake with the sign of ΔH. This suggests that post-laboratory sessions are valuable opportunities to discuss issues related to the particular practical session. They may also facilitate report writing and enable communicative competence.

The major change for 2001 involved dividing the experiment into two sections, experiments 4a and 4b. A simple experiment, 4a, focused on procedural issues. It was devised to introduce students to the techniques of weighing on a top-loading balance and reading a thermometer calibrated to 0.2 degrees. The concepts introduced at this stage were limited to endothermic and exothermic reactions. The second experiment, 4b, was exactly the same as the one performed in 2000, the focus was on declarative knowledge namely, Hess's Law. Three demonstrators and some of the students were interviewed after the experiments had been carried out. They agreed that this division of the experiment into two sections had been effective. The demonstrators' comments on experiment 4a:

> 'Definitely had its merits, probably don't realize how important it was in terms of a stepping stone but if you know how big and deep it is from nowhere to the experiment from last year [Hess's Law] you can see that it is very necessary to get them to use the thermometer, things you took for granted they would know how to use and they didn't; a guy actually asked me 'what is that shiny stuff?' The students [in 2001] were less all over the place, less confusion, they got things so much quicker, there was direction'. (Interview, demi AT).

> 'I think even if you would have kept those old balances and used them to introduce ... the fact that you did 4a, that could have worked out well.' (Interview, demi BJ).

A student's perspective on experiment 4a:

> 'The first experiment (4a) is not as exciting as Hess's Law and you are not looking at the real law but the procedures ... practise a little bit before you actually do the crux of the experiment. In the long run you focus more on the Hess's Law experiment (4b) because of 4a, if we hadn't done it we would have been lost in the experiment on Hess's Law.' (Interview, student No. 58).

8. Discussion

The difference between the two laboratory sessions was so marked that it hardly needed careful observation to notice. Instead of ragged, stressed staff and students, all concerned emerged from the 2001 practical with an organized set of results to interpret. Students valued the time to discuss the results obtained by their group and for one student it was an important stage of the practical session:

> '...I also liked the presentation that Dr D. made at the end of the prac because I didn't understand what the experiment was about at first but after her presentation I had a better idea of what was expected'. (Questionnaire, student No. 70).

Table 2 Comparison of findings for Hess's Law experiment between 2000 and 2001

	2000	2001
Pre-lab discussion	Lasted 7 minutes and dealt with procedural information and how to use apparatus.	Lasted 20 minutes, no mention of equipment or procedure.
	Little mention of Hess's law, the aim of the experiment	Focused mostly on conceptual issues and calculation of results
	Few questions posed by students	Several questions posed to students and some initiated by students — questions generally on conceptual issues
The lab session	Lasted 2½ hours	Lasted 1 hour
	Demonstrator's time taken up mostly with demonstrating use of balance	No problems with balances. Students spontaneously learned to tare balances
	Questions on use of thermometers	No problems reading thermometer
	Student questions around use of balance	Students' questions related to interpretation and calculation of results
	Experiment done twice	Experiment done once
Post-lab discussion	No pooling or discussion of results due to lack of time	Lasted 20 minutes
		Full discussion on procedural aspects such as spotting of anomalies, averages etc.
		Discussion of laboratory report and post-laboratory questions and curriculum issues
Lab reports	Inaccurate results obtained	Accurate results obtained
	Only a few students reported all results for their group	Whole group's results reported
		Procedural issues thoroughly discussed
	Main ideas of experiment often overlooked	Main ideas of experiment grasped

The separation of the exercise into two experiments facilitated students' ability to process information:

'I don't think you could have been able to do 4b if you actually didn't do 4a. It was more like a path that would take you to 4b. It's more like you're travelling a certain distance in order to reach your destiny. So 4a was more like that kind of path. You had to go through 4a and understand what actually you are supposed to do in 4b. It was more like a basic or whatever, a starting point. You had to understand what endothermic is, understand how can you be able to identify something endothermic. Ja, you have to understand the basics and then you can actually understand 4b if you know 4a.' (Interview, student No. 68).

This quotation highlights a particularly difficult conceptual issue, that of linking experimental observations of exo- and endothermic changes to the theoretical ideas of enthalpy change, system and surroundings. A further benefit of the additional exercise was that it allowed opportunities to discuss these issues.

We were fortunate to be able to structure the practical course to accommodate the extra experiment, 4a. This may not be possible in all cases. The use of the mechanical balances was the main source of noise in 2000. If electronic balances are not available, one way to decrease the noise would be to pre-weigh the sodium hydroxide, allowing students to focus on the temperature measurements relevant to Hess's Law.

The absence of noise in the practical was clearly observed by the students' ability to process information germane to the exercise itself rather than attention being diverted to learning how to use antiquated balances or trying to interpret the scale on a thermometer – a skill that had been mastered the previous week. This allowed adequate selection, organization and reflection on the various aims and purposes of the experiment.

Flavell describes cognitive and metacognitive processes and works with metacognition as a monitoring process.[16] He divides metacognition into metacognitive knowledge and metacognitive experiences. Metacognitive knowledge consists of long-term stored knowledge which may be retrieved and used during a cognitive endeavour. Metacognitive experiences are conscious ideas, thoughts or feelings related to any part of the endeavour.

There was evidence of metacognition as shown in this response from one of the students:

'I have learned that experiments are not only about procedures [accuracy, etc.] but observations and questioning things. I've learned to use chemical concepts from lectures both with experiment. However not only the experiment helped me with the above-mentioned facts but most importantly it said to me: Don't accept everything you are told, not that it's wrong BUT question them. How is that happening like that?' (Questionnaire, student No. 39).

'In this experiment I've learned that you must not just do the experiment without understanding it and you must come prepared.' (Questionnaire, student No. 19).

Several students also mentioned procedural issues and social factors in their responses to the questionnaire:

'...I did not find exactly the same values in this experiment, but those that I found were close, meaning there might have been an error somewhere — maybe the reading of the thermometer or something.' (Questionnaire, student No. 3).

'...I've also learnt that you enjoy the prac when you are working with people who enjoy it as well and when you've got a good demonstrator'. (Questionnaire, student No. 68).

Although practical sessions are not ideal environments to learn chemical concepts there was also evidence of deep processing of information:

'It's not a matter of getting correct results or about copying, but about what you understand by the results you got, and trying to find out why you obtained those particular results. I have realized that the course has helped me understand basic things which were not put clear to me in Matric'. (Questionnaire, student No. 65).

Roth *et al.* observed a teacher and students who were doing an experiment in physics.[3] They have shown that students could not conceptualize the scientific idea required by the teacher as they did not share his understandings and explicit theoretical frameworks. Without prerequisite theory, students from disadvantaged backgrounds would be unable to construct order from a series of observations. As a result of clearly establishing background theory, students were able to construct phenomena and correctly identify instances of experimental error as the quotes above show.

9. Conclusions

Many of the problems isolated in the 2000 practical were solved in 2001 but some remain and it may be asking too much of the practical exercise to solve these problems. In both years students had prepared for the experiment on Hess's Law. The session in 2000 placed too many demands on students in the form of both manipulative and cognitive skills, thus increasing the noise level for the experiment. Basic concepts such as the application of the mole and how to carry out the calculation of ΔH are not best tackled in practical sessions.[10] However the experience described in this paper shows that removing extraneous noise from a practical exercise can at least allow discussions about these issues to take place. Our findings show that the actual experimental design can overwhelm even those students who prepared in advance for the practical by reading the practical manual and preparing a flow diagram. Designers of experiments should try to reduce noise in laboratories at all levels to allow students time to reflect on the conceptual and procedural aspects of the experiment.

The Hess's Law experiment is a closed activity. Students know the answer, thus they can reflect on procedural aspects of the laboratory as well as on the general purpose of the experiment and make the connection to theory. We believe that there is a place for closed activities for those students who do not have the prerequisite theoretical framework and who have not had the opportunity to acquire laboratory skills.

Acknowledgements

We thank the National Research Foundation and the UCT Research Committee for financial support, and Prof. Susan Bourne and Ms Karen Wallace, Chemistry Department, UCT, for helpful comments on this paper.

References

1 B. Davidowitz, F. Lubben and M. Rollnick, *J. Chem. Educ.*, 2001, **78**, 247–252.
2 A. Berry, P. Mulhall, J.J. Loughran and R.F. Gunstone, *Aust. Sci. Teachers' J.*, 1999, **45**, 27–31.
3 W-M. Roth, C.J. McRobbie, K.B. Lucas and S. Boutonné, *Learning and Instruction*, 1997, **7**, 107–136.
4 M. Rollnick, S. Zwane, M. Staskun, S. Lotz and G. Green, *Int. J. Sci. Educ.*, 2001, **23**, 1053–1071.
5 A.H. Johnstone, *J. Chem. Educ.*, 1997, **74**, 262–268.
6 A.H. Johnstone and K.M. Letton, *Educ. Chem.*, 1991, **28**, 81–83.
7 A.H. Johnstone and A.J.B. Wham, *Educ. Chem.*, 1982, **19**, 71–73.
8 M. Rollnick, S. Allie, A. Buffler, L. Kaunda, B. Campbell and F. Lubben, *Proceedings of the 7th Annual Conference of the Southern African Association for Mathematics and Science Education*, Harare, Zimbabwe, 1999, 366–371.
9 P. Ramsden, *Learning to Teach in Higher Education*, Routledge, London, UK and New York, USA, 1992.
10 D.S. Domin, *J. Chem. Educ.*, 1999, **76**, 543–547.
11 S. Kemmis and R. McTaggart, *The Action Research Planner*, 3rd edn., Deakin University, Victoria, Australia, 1988, pp. 9–46.
12 R.A.D Wentworth, *Experiments in General Chemistry*, 5th edn., Houghton Mifflin, Boston, USA, 1999, pp. 123–135.
13 M.S. Silberberg, *Chemistry, The Molecular Nature of Matter and Change*, 2nd edn., McGraw Hill, Boston, USA, 2000, pp. 241–246.
14 B. Davidowitz and M. Rollnick, *Aust. J. Educ. Chem.*, 2001, **57**, 18–24.
15 W.J. Conover, *Practical Nonparametric Statistics*, Wiley, New York, USA, 1971, pp. 309–314.
16 J.H. Flavell, in *Children's Oral Communication*, (W.P. Dickson, ed.), Academic Press, New York, USA, 1981, pp. 35–60.