FROM COMPLIANCE TO INTEGRATION: MICROSCIENCE ENABLES LEARNING THROUGH PRACTICAL ACTIVITIES

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ABSTRACT

University courses preparing students to teach school science should be models of good practice rather than reflections of accepted behaviour in schools. At the same time the requirements of the national school curriculum and the real difficulties faced by teachers must be catered for. Such thoughts led us to revise a course in chemistry for final (4th) year student teachers of Physical Sciences. The revision is continuing, being informed by experiences so far, which we report upon here. Extensive adoption of microscale activities enabled greater student access to hands-on, minds-on experiences, whilst improving safety and reducing environmental impact. *[African Journal of Chemical Education—AJCE 9(3), November 2019]*

INTRODUCTION

The context of this paper is a fourth-year course in the Wits University BEd curriculum for future teachers of the secondary school subject Physical Sciences. In designing this course attention was paid to the national school curriculum for the subject, which specifies the content and assessment of that curriculum [1]. A section (2.5) of the current curriculum document is devoted to 'Overview of Practical Work' where it is stated:

> *"Practical work must be integrated with theory to strengthen the concepts being taught. These may take the form of simple practical demonstrations or even an experiment or practical investigation….Some of these practical activities will be done as part of formal assessment and others can be done as part of informal assessment. Below is a table that lists prescribed practical activities for formal assessment as well as recommended practical activities for informal assessment across grades 10 to 12."*

Elsewhere in the document (2.2 Specific Aims of Physical Sciences) the first sentence of the above paragraph is explicitly confirmed:

> *"Practical activities as used in this document will refer to practical demonstrations, experiments or projects used to strengthen the concepts being taught."*

The reference to prescribed practical activities being for formal assessment carries with it the implication of a contributory weight to the overall assessment of the learner, which is 15%. This is quite a significant weight, when it is realized that the final examination in any one year counts 75%. Furthermore, if the practical activities really do strengthen the concepts being taught, then learners benefit twice (firstly by marks gained directly when doing the practical activities, and then secondly, by improved exam marks).

A framework for practical activities in secondary schools in South Africa is then clearly in place and encouraging. However, the realities are less encouraging. Many schools lack resources for the practical work, and have teachers who are not competent to manage it and use it for the principal purpose, lack technical support and maybe overloaded with teaching duties. They are also under pressure from all sides (department officials, the school principal, parents and the media) to improve the pass rate. The implication of this is the familiar exam fixation, and when this is coupled with doubts as to whether concepts can be strengthened by practical activities, the consequence may be that these activities are either minimized in the teaching program, or in some way are fudged. In a nutshell, compliance characterizes the obligations of practical work in many secondary schools.

THE AIMS OF PRACTICAL WORK

Although the South African curriculum document for Physical Sciences is explicit about the purpose of the practical activities (especially the prescribed ones), other aims are also often identified for practical work. Indeed, numerous authors over some decades, have written not only about the aims but also about the meaning of practical work. A recent review of this field of debate by Wei and Li (2017) argues that “practical work is essentially a special kind of science practice that provides a special situation and an educative environment in which newcomers can learn science”. [2] This very broad description of meaning is something our student teachers should be aware of, but at the same time they need to be clear about the focus required by national policy.

For the latter purpose we have found the short list of aims put forward by Woolnough and Allsop [3] more than 30 years ago, to be a manageable framework for our purposes. In shortened form this is:

1. Motivation
2. Developing practical skills
3. Learning the scientific approach
4. Gaining a better understanding of theoretical aspects of the subject.

Nivalainen, Askainen and Hirvonen [4] adopt a similar short list (but adding “enhancing social and learning skills”) in their recent research into third year pre-service physics teachers’ views.

There are many reports in the literature suggesting that teachers often have confused ideas about the aims of practical activities they plan. They may recognize all four of the Woolnough and Allsop aims and include a number of them in their lesson plans. This tends to result in unrealistic expectations of learner achievement, especially as regards the fourth aim of better understanding of concepts [5] [6] [7] [8].

TOWARDS BETTER UNDERSTANDING THROUGH PRACTICAL ACTIVITIES

In a conclusion to their study, Abrahams and Millar [7] suggested that the cognitive challenge of linking observables to ideas [9] has not been adequately recognized. This suggestion has been taken to heart in more recent research on the learning of concepts through practical activities, and much positive light has been shed on what it takes to achieve the aim of better understanding. This research has come from several different countries and contexts. [10] [11] [12] [13][14]

Taken together the outcomes suggest that to achieve better understanding of theoretical aspects through practical work ‘laboratory overload’ must be avoided, implying:

- learners should be as well prepared as possible
- instructions should be as simple as possible
- manipulations should be as easy as possible
- there should be ample time for reflection.

It may be noted that avoiding ‘laboratory overload’ might not only improve learning of concepts, but improve attitudes to the course [15]

PHYSICAL SCIENCES TEACHER PREPARATION IN A BEd IV COURSE

As part of the final year course for prospective Physical Sciences teachers at our university, students engage in practical work in chemistry for one 3 hr session per week over about 10 weeks. Arising from observations of these sessions and of the lectures over the same period gave rise to concerns:

- practical activities were sometimes weakly-related to lecture content;
- practical activities did not match the prescribed practical activities in the school curriculum;
- most of the supervision of the lab session was by post-graduate students who did not give or participate in the lectures;
- student lab reports from a session were only submitted in the following week, and marking of these was only completed the following week;
- the conduct of labs could be characterized overall as ‘compliance’, just as found in many secondary schools;
- ‘integration’ of labs and lectures was weak and the course was failing to prepare students to implement the national policy statement in the classroom.

Following discussion between the course lecturers, post-graduate student demonstrators and technical staff, it was decided to constitute a project to address the shortcomings we had observed. The general desirability of pre-laboratory preparation by university students was clear [15][16]. We also took into account the suggestions arising from recent research towards improving the likelihood of achieving a better understanding of theoretical concepts. The initiatives we were able to take in the first year and a half of the project are briefly outlined below:

Alignment of practicals with lectures, tutorials

This implied paying attention to the actual content and objectives of the lecture component of the course, achieving consistency in terminology and emphases, and also addressing the relevant concepts in the same week. Practicals, wherever possible, also reflected prescribed practical activities in the school curriculum. Practicals were referred to in the lectures both before and after the relevant lab session, to an extent dependent on the case.

Computer-based pre-lab testing

Multiple-choice questions were designed which focused on the specific content and concepts relevant to the practical concerned. In the first year of the project (2018) students were required to score a minimum of 60% (by repeated attempts if necessary) for admission to the lab session. This policy was amended in 2019, with the score on the pre-lab test being included in the mark for the practical.

Converting to microscale

The conversion to microscale was motivated by the objective of easier manipulation and shorter time for completion. Other expected benefits were cost-savings and improved safety, as well as reduced environmental impact. The specific kits used were the RADMASTE Advanced Microchemistry kits. [17][18]

Lab supervision and reporting

Lecturers collaborated with technical support staff and demonstrators to achieve a simpler and more focused lab experience for students. Lecturers undertook supervision to a greater extent, students were required to submit lab reports within 2 days of the lab session, and demonstrators' marking was completed in time for the next lab session.

Tests and exam

Prac-related questions were included in class tests (2019) and the final exam (2018). This did not mean a need to recall specific features or details, but simply that the lab experience would sometimes be the context for a question about particular concepts – more like a prompt to say please recall you worked with these concepts in a lab session previously, so you should find this question rather easy.

OUTCOMES

Structured interviews were conducted with 9 (out of 36) volunteer students at the end of the course in 2018. The interviews took place after the final exam for the course had been written and marked. The research questions were characterized as:

A. Link of prac work to lecture content
B. Online features of the practicals
C. Format of the practicals

As may be deduced there was no attempt at this stage to measure the impact of the practical activities on student understanding.

Our analysis of the responses in the interviews yielded the following:

A. Link of prac work to lecture content

Students clearly saw the linkage and volunteered this observation under B as well. Included in this section were questions about an exam question and its relationship to one of their practicals.

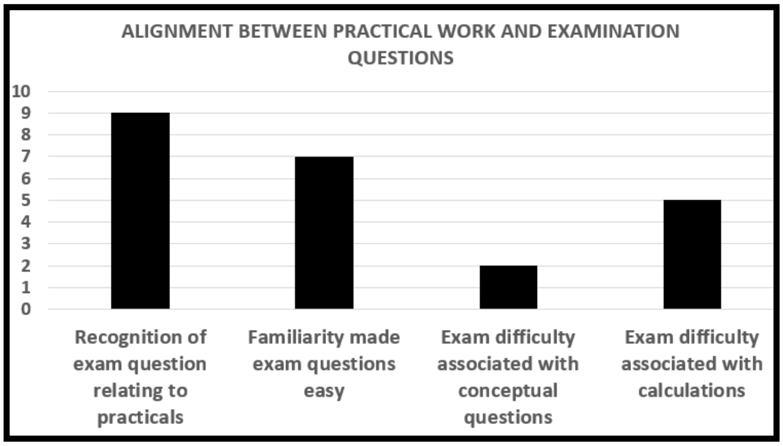

Figure 1: Responses on alignment between practical work and examination (9 students)

As shown in the Figure 1 above, all the participant students (n=9) could recognize the relationship between examination questions and concepts covered during laboratory experiment sessions. Commenting on the nature of examination questions, seven students linked the simplicity of questions to familiarity from the laboratory sessions, two students related the difficulty of exam questions to the conceptual questions involved, whilst five students linked their difficulty to inability to figure out appropriate formula for calculations. We discuss this further after dealing with B and C below.

B. Online features of the practicals

Students supported the pre-lab tests commenting

- important for lab preparation
- successfully aligned with both pracs and lectures
- “a bridge between content and pracs”
- some wanted more chances to re-do the tests, after the lab session.

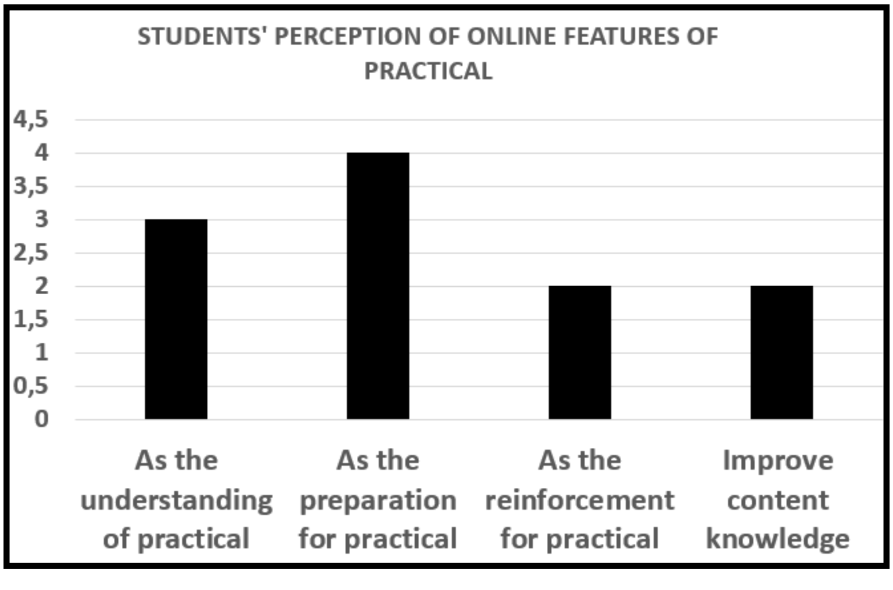

Figure 2: Responses on online features of the practicals

C. Format of the practicals

Students made mostly positive comments on the ‘format’ – a term covering a number of aspects as the following points show

- lab manual clarity
- questions embedded in the lab instructions
- easy procedures
- micro-kits easy to use (students had extremely limited previous experience)
- lots of potential for the micro-kits in schools (but anxiety about learner discipline)

All of these majority comments are encouraging, and we have continued to refine the initiatives of 2018 during the same course in 2019. The overall impression so far is that the students definitely saw the practical activities as an integral component of the course. They imply that it has been a benefit for them in their understanding of the course content: however, the quantitative information that might confirm this is yet to be acquired.

In the meantime, we are carrying forward a disappointment as regards the exam question mentioned above. This was a question that was answered badly by the students, despite its obvious relationship with a practical activity that they had recently completed.

It is worth giving some of the details on this because in the end it has re-taught us a lesson (see the 4 points of advice listed earlier).

The practical activity to which the question referred was concerned with an acid-base titration. It had 3 stages (i) preparing a standard solution of oxalic acid, (ii) standardizing a given sodium hydroxide solution with the oxalic acid solution, (iii) using the sodium hydroxide solution to determine the concentration of acetic acid in a commercial vinegar. All of these are prescribed practical activities in the grade 12 school curriculum. Traditional scale equipment was used, but it soon became evident that very few of the students had prepared a standard solution or done a titration before, despite the prescribed nature of these activities in the school curriculum. The majority of students did not complete all three parts even though the lab session ran into extra time.

In writing up their lab reports, students had (i) to calculate the concentration of the oxalic acid solution they had prepared and then (ii) they had to use this information, together with the results of the titration with sodium hydroxide, to calculate the concentration of the latter. Finally, they had to use this calculated concentration in order to work out the concentration of acetic acid in (iii) in the sequence.

In the related exam question the calculation under (i) was applied using a given mass of oxalic acid dihydrate (formula given). Then the calculation under (ii) was applied using given average titration volumes. They were required to write a balanced chemical equation for the titration reaction. Finally, (iii) there was a question about why the given indicator (phenolphthalein) was chosen. It was of course, a strong base-weak acid titration (but not so-identified in the exam question) and they had used phenolphthalein in the practical activity.

The marks assigned to these three questions in the exam are compared with the class average mark obtained in the table below:

Exam Q no.	(i)	(ii)	(iii)
Full mark	2	3	2
Class average	1.30	0.56	0.81

Considering how closely the exam questions follow the first two stages of the relevant practical activity, the outcome is disappointing. We may highlight the task of writing a balanced chemical equation as particularly surprising:

1. only 6 (out of 36) students recognized the required mole ratio of 2 NaOH: 1 Oxalic acid;
2. 11 students wrote the formula of the oxalic acid dihydrate in the equation, not realizing that the hydrate nature of the solid is irrelevant in aqueous solution;
3. 18 equations showed ‘crazy’ products. (eg 2 $NaCO_2$ + 3 H_2O; $2H_2O$ + 2 NaCOOH).

It should be noted that the 2:1 mole ratio of the titration reaction was frequently referred to in the lab manual, although the balanced equation was not given. A question in the lab manual however, specifically required them to write the balanced equation of $H_2C_2O_4$ (aq) with NaOH (aq), and there were related sub-questions (eg How many protons are transferred by one oxalic acid molecule? What name do we give to an acid that transfers these many protons per molecule?). The balanced equation was of course required, in order to make the necessary calculation of the concentration of the sodium hydroxide solution. Marking of lab reports should have corrected mistakes in this regard; perhaps they were but students paid no attention. We plan to explore the feasibility of online assessment of lab outcomes, along the lines described by Whitworth and Wright. [19]

The widespread appearance of ‘crazy’ products suggests that the entire basis of acid-base chemistry is very weak and that their previous experience of formula and equation writing has been narrow. This revelation is echoed by other evidence in the exam answers in relation to electrochemical reactions.

In the context of a fourth year course for Physical Sciences teachers-to-be, one can argue that the actual laboratory context should not have been important for the students in the exam. The substance of the exam questions is quite normal and a good outcome could be expected without any benefit from the practical experience. It was definitely not the case that success depended absolutely on having done this practical. This might imply that the lab experience was so negative that it actually handicapped the students when answering the exam questions. Johnstone has reported instances suggesting such an effect [20]. This could explain why some earlier research has queried the benefits of practical work for gaining a better understanding [21]. Whatever the truth of the matter, we can draw one definite conclusion from the outcome: we must avoid ‘laboratory overload’ as, of course, we had planned to do!

CONCLUSIONS

Our transition from compliance to integration in the context of a BEd course in chemistry continues to take place. Students support the initiatives taken so far in this regard, although substantive evidence of improved understanding is yet to be gathered. Their support suggests that they appreciate at least the potential benefits of the integration. We can clearly do better and avoid mistakes. It is also evident that changing several of the practical activities from traditional scale to microscale helped students gain hands-on experience. We were able to reduce the number of students per group to two, in place of the three or four that previously had been the standard. Despite the lack of familiarity with this equipment they had no difficulty with using it, as we have found in other contexts too.

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