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Does the pedagogy for the teaching of first year undergraduate laboratory practicals still meet the needs of the curriculum?

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Abstract

This work examines the teaching approach for chemistry laboratory practicals for first year undergraduate students to determine if the underpinning pedagogical strategy meets the requirements for these students for the remainder of their undergraduate programme. This is based on the knowledge, skills, content and learning outcomes for undergraduate chemistry courses. This work aims to enhance the first year experience of chemistry education by facilitating greater student engagement and "deeper" learning of relevant content during practical laboratory experiences by focusing on the learners' needs. During this research, a survey of undergraduate science students from 2nd, 3rd and 4th years was carried out to determine if first year chemistry practicals facilitated the development of skills needed in further science education. It concluded that overall there was a positive response to first year laboratory practicals, that students engaged with them and felt they assisted with skills required for subsequent years of undergraduate study. Participants were most satisfied with the organic chemistry experiments while, for the physical/analytical chemistry experiments, the results obtained reiterated difficulties with mathematical calculations that are accepted as an issue in other aspects of third level STEM (Science, Technology, Engineering and Mathematics) subjects. As a result of these findings, modifications that were made to the laboratory practical element included a pre-populated workbook supplied to the students and the introduction of pre-laboratory questions to be completed by each student before each session to reduce cognitive load and improve the students' knowledge and understanding of the purpose and potential outcomes of each laboratory practical. Also, the total first year chemistry syllabus was re-organised, as was the scheduling of the experiments to synchronise the theory lectures with the experiments as far as was practical.

Keywords: Chemistry, First year undergraduate, Laboratory curriculum, Skill requirements

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Introduction

Chemistry education research is now a well-established discipline. There are many journals and experts dedicated to the subject and a great deal of research undertaken and published (Chemical Education Research and Practice, Journal of Chemical Education, International Journal of Science Education). How much of this research has made it into practice is an unknown commodity, and the question of whether those not involved in research are actually using the research of others to improve their teaching is also being questioned. Childs (2009) has highlighted the gap between results of research and their application into chemistry teaching practice. First year chemistry laboratory practicals seem to have resisted much of this research and suggested changes. Certainly most practicals now have aims and learning outcomes but still follow the controlled predictable experiments highlighted in the survey conducted by Meester & Maskill in 1995.

The Purpose of Laboratory Practicals in Chemistry

In these recessionary times, the high cost of laboratory practicals has again put them in the spotlight for cost: value comparison and figures date back to 1982 when the ratio of cost was 15:1 for lecture to laboratory costs (Wham & Johnstone, 1982). There are many arguments on the need and purpose of laboratory practical experiments, although the RSC (Royal Society of Chemistry) continues to have a minimum requirement of 400 hours in the accreditation of their degree courses. The emphasis should be on the changes to the pedagogy of conducting laboratory practicals to improve their value rather than elimination and these arguments are many in the literature (Boud, Dunn & Hegarty-Hazel, 1989; Bennett, Seery & Sovegjarto-Wigbers, 2009) .

Focusing solely on first year science, the chemistry laboratory practicals emphasise building up a basic skills set that students will use in future years to acquire their undergraduate degree. The purpose is that they can become able practitioners of chemistry. These practicals aim to teach students how to conduct laboratory experiments and the learning is in terms of the cognitive skills for recording and observation including how to write a report using the data acquired with some emphasis that all reports must have a conclusion.

Missing from the previous aims is the development of scientific enquiry Klopfer, Welch, Aikenhead & Robinson (1981) suggest that the development of scientific enquiry involves the following 4 processes:

- Observing and Measuring
- Seeing a problem and seeking ways to solve it
- Interpreting data and formulating generalisations
- Building, testing and revising a scientific model

In the past thirty years the type, format and underpinning pedagogy of chemistry practicals has changed little in comparison to the radical change which has taken place in other aspects of research technique and industrial technology and analysis. The Forfas report on Skills in the Biopharma-Pharmachem sector has highlighted this and noted in chemistry disciplines that programmes need to reflect industry practice: "While the fundamental principles of chemistry have not changed, the research landscape and industry practice is constantly evolving and should be reflected in HEI programmes" (Forfás, 2010, p.98).

Research Aim and Objectives

The purpose of this study is to review if first year laboratory practicals in chemistry education are successful in developing the skills needed for subsequent undergraduate education and

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ultimately for research or industry. This should facilitate graduates with core competences in one of the sciences to understand where their specialism fits into the overall science and technology sector.

In the School of Chemical and Pharmaceutical Sciences at DIT, students enrolled on primary Chemistry, Biology and Physics degrees for Level 7 and 8 courses will complete a standard set of laboratory practicals that are tried and tested to cover skills and content relevant to their modules. The majority of practicals are in an expository style of teaching where the students are given a procedure in a manual and, if followed correctly, will deduce a pre-determined outcome from their data. Boud *et al.* (1989) describe these "recipe labs " as controlled exercises rather than experiments and Johnstone & Wham (1994, p.72) commented, "*students can be successful in their laboratory class even with little understanding of what they are actually doing*". There are 24 x 2 hour laboratory sessions provided over 2 semesters that cover all aspects of general, physical, analytical and organic chemistry in the School of Chemical and Pharmaceutical Sciences.

Part of this research is to question how effective first year laboratory practicals are for deepening students' knowledge. Where we use laboratory practicals to complement the lecture material this facilitates reinforced and deep learning takes place. Reid & Shah (2006) examined the role of laboratory work in university chemistry and under the heading of skills related to learning listed : making chemistry real, illustrating ideas, empirical testing ideas and teaching new ideas. However, these aims depend on the quality of the laboratory demonstrators and that the laboratory schedule is synchronised with the content of the module lecture material. These are variables that are not necessarily under the control of the School or the laboratory supervisor.

First Year Student Retention

For most first year undergraduate chemistry courses, there is an overlap with the second level Leaving Certificate chemistry syllabus as the entry requirements do not include a specification that chemistry must have been studied at second level. This adds to the difficulty of modifying first year practicals where the possibility of boredom from students who have completed leaving certificate chemistry is countered by the cognitive overload suffered by those students who have not. This leads to a high level of attrition in the first year of third level science courses and HEIs (Higher Education Institutions) are looking at intervention programmes to engage students in chemistry topics (Regan, Childs & Hayes, 2011).

Assessment and feedback have been highlighted as a method of early student engagement in university (Woods 2010, p.33). This is particularly true of chemistry so that the student can understand how well they are coping with the course. The aspect of feedback and assessment will also be examined in this survey.

Methodology and Methods

A survey was prepared and distributed to 2nd 3rd and 4th year undergraduates in DIT in 2012 (Appendix 1). In total, 75 students completed the survey and the distribution of principal subjects and general statistics was as presented in Table 1. The survey provided the opportunity to collect both quantitative and qualitative data as closed and open response questions were incorporated. The key questions to be answered were whether students found the laboratory practicals that they had undertaken in first year were of benefit to providing the skills they required for their subsequent undergraduate years and to gain information on

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specific areas of chemistry and how they coped with the laboratory sessions. The questionnaire followed the Likert technique with a 4 point scale.

Questions 1 to 5 were data gathering questions on age profile, gender, major subject course and stage. Questions 6 to 13 were based on the general attitudes to laboratory practicals and the response options were *Strongly Agree; Agree; Disagree* and *Strongly Disagree*. Questions 14 to 17 allowed the type of practical to be broken down into specific areas of chemistry such as *Organic, Physical, Analytical Chemistry* and *Qualitative Chemistry*. The survey was distributed by hand at the end of laboratory or teaching session and the students were allowed approximately 15 minutes for completion. There was a consent form attached along with brief information about the purpose of the research project.

Results

There was an almost even split in the gender of the respondents with 37 males and 38 females. Table 1 below shows the primary discipline of study of survey participants.

Table 1 Primary subject studied by survey respondents

Distribution of students by primary subject				
Primary subject	***Physics***	***Chemistry***	***Biology***	***Phy & Chem***
No. of students	11	45	16	3
Total Number of students	17	55	56	9
% Response Rate	65	82	29	33

The overall number of students in each year who responded was: 65 in 2nd year; 3 in 3rd year and 7 in 4th year. Results for Question 5 on the time spent on reports were that over 75% of students spend greater than 30 minutes to complete a first year chemistry practical report.

Understanding of Experiment and Subject Matter

Questions 6 and 7 concerned understanding of the subject and the experiment. The data shows that over 90% of students *strongly agree* or *somewhat agree* with this statement; however regarding understanding of the purpose of the experiment after completion this drops to 61% of respondents. The difficulty of cognitive overload in practical experiments is well documented. The cognitive gain is reduced as students' working memory space is occupied with instruction, manipulation, recording etc. Reid & Shah (2007) suggest that the amount of actual learning is minimal due to the vast amount of information to be understood, and Johnstone & Wham (1982) reported that the amount of cognitive overload was so great that some students repeated familiar tasks in laboratory experiments to avoid new ones. Figure 1 is a schematic of these sources of information and the prior knowledge that students must possess in order to interpret the outcome of a chemistry experiment. Schroeder & Greenbowe suggest that "Simply replicating what chemists do in laboratories will not enhance the learners' understanding of chemistry (Schroeder & Greenbowe, 2008, p.149).

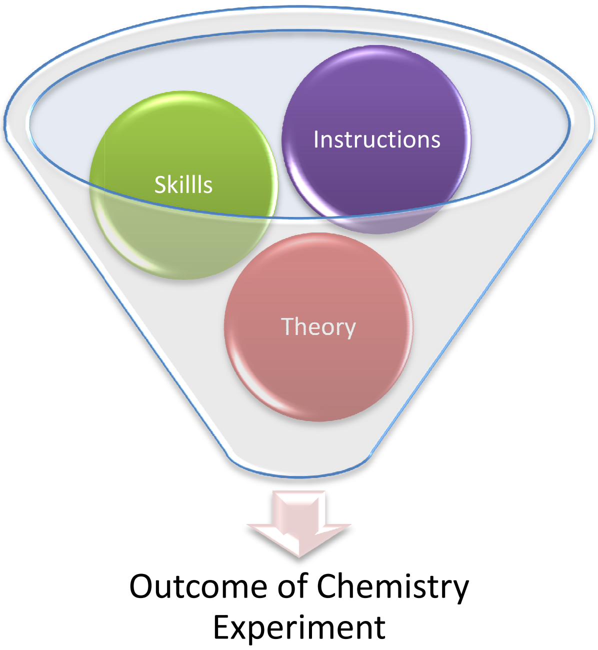

Figure 1 Schematic of the sources of information and prior knowledge for students in undergraduate laboratories

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Questions 9 and 11 are related to the amount of information the students have to cope with in a practical session. The number of students who agreed that they never read the instructions in the manual prior to going to the laboratory was approximately 50%, whereas those who thought that there was too much information given to know what was going on was only 33%. Those who felt the written instructions were easy to follow was 80%. The application of skills learned to laboratory work for future years was 85% positive; further analysis of this revealed that the level of agreement by Physics and Biology undergraduates was equal to that of Chemistry students.

Questions 14 to 17 deconstructed the experiment type into *Physical Chemistry, Qualitative Analysis, Organic Chemistry* and *Analytical Chemistry*. Some examples of the experiments were listed as a reminder. For the section on *Physical Chemistry* and *Analytical* there were three questions. “Did you understand the purpose of the experiment?”; “Did you learn how to set up the apparatus?” and “Did you understand the calculations?” There was a four point scale: *very good; good; fair; poor*. It is assumed the response *very good* and *good* indicates adequate understanding.

The responses to the questions on understanding the purpose of the experiment showed that for *Analytical, Physical* and *Organic Chemistry* >85% understood the purpose of the experiment whereas for *Qualitative Analysis* only 59% understood it (see Figure 2 overleaf).

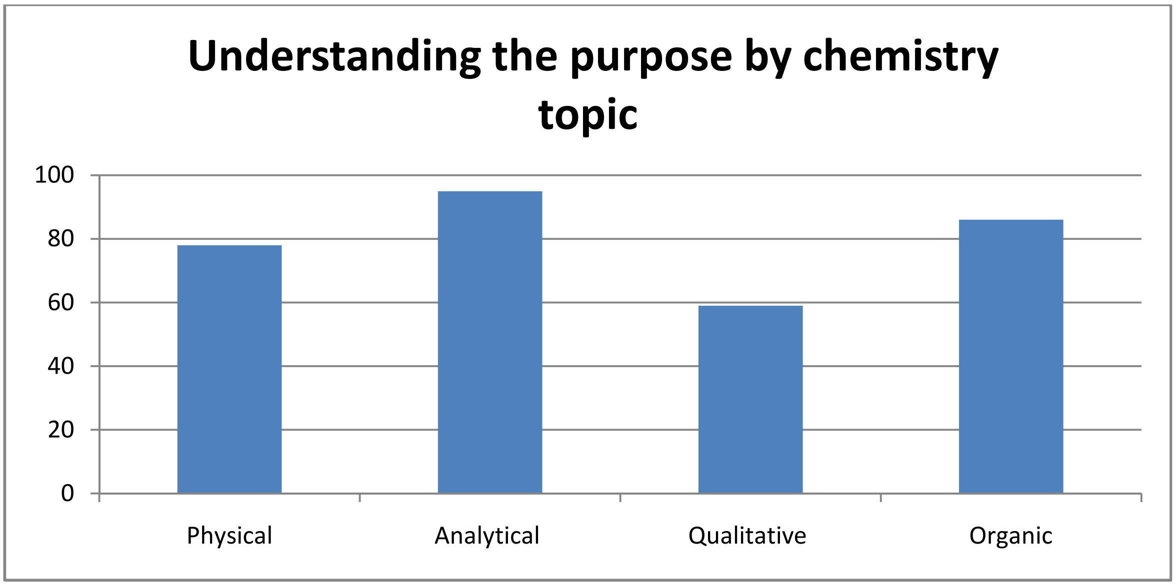

Figure 2 Responses to questions on understanding the purpose of the experiment by chemistry area

Over 95% of the participants reported that they had learned how to set up apparatus for all three categories of experiments (there was no apparatus set up in *Qualitative Analysis*). The question on understanding the calculations only relates to *Analytical* and *Physical Chemistry* and here the responses *fair* and *poor* increase dramatically. For *Physical Chemistry*, 48% of responses were in the *fair* and *poor* categories and *Analytical Chemistry* had 25% between these categories (see Figures 3 and 4).

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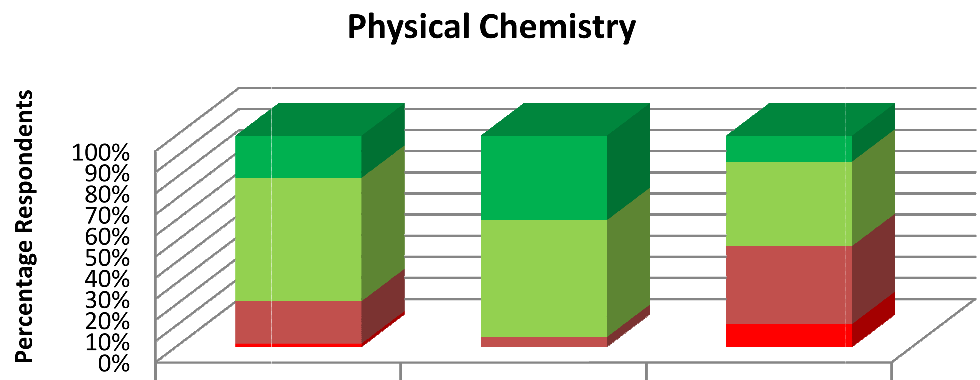
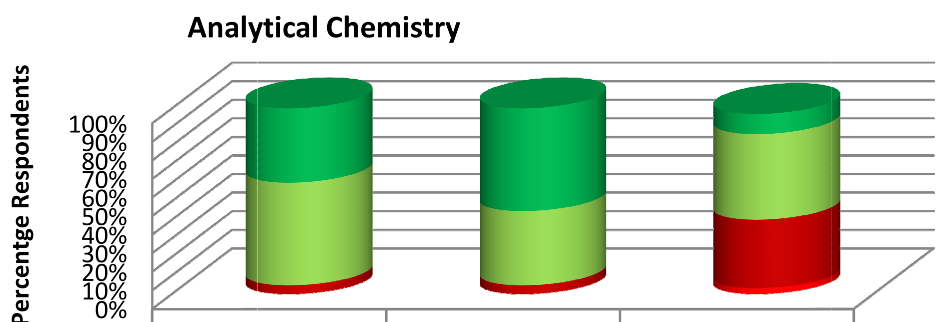


	Understand purpose of experiment	Learn apparatus setup	Understand calculations
Excellent	20%	40%	12%
Good	58%	55%	40%
Fair	20%	5%	37%
Poor	2%	0%	11%

Figure 3 Responses on Physical Chemistry Practical sessions



	Understand purpose of experiment	Learn apparatus setup	Understand calculations
Excellent	40%	55%	11%
Good	55%	40%	46%
Fair	5%	5%	37%
Poor	0%	0%	3%

Figure 4 Responses on Analytical Chemistry Practical sessions

The last section of the survey allowed for free responses on what was the *Best Part* and *Worst Part* about 1st year Biology, Chemistry or Physics practicals. For Chemistry, two topics that came up repeatedly for the *Best Part* were *Organic Chemistry* and gaining practical experience (18% and 50% respectively) as presented in Figure 5. Guest lecturers are where experts from the field, either from an industrial, research or public sector body would come in and give the students a lecture.

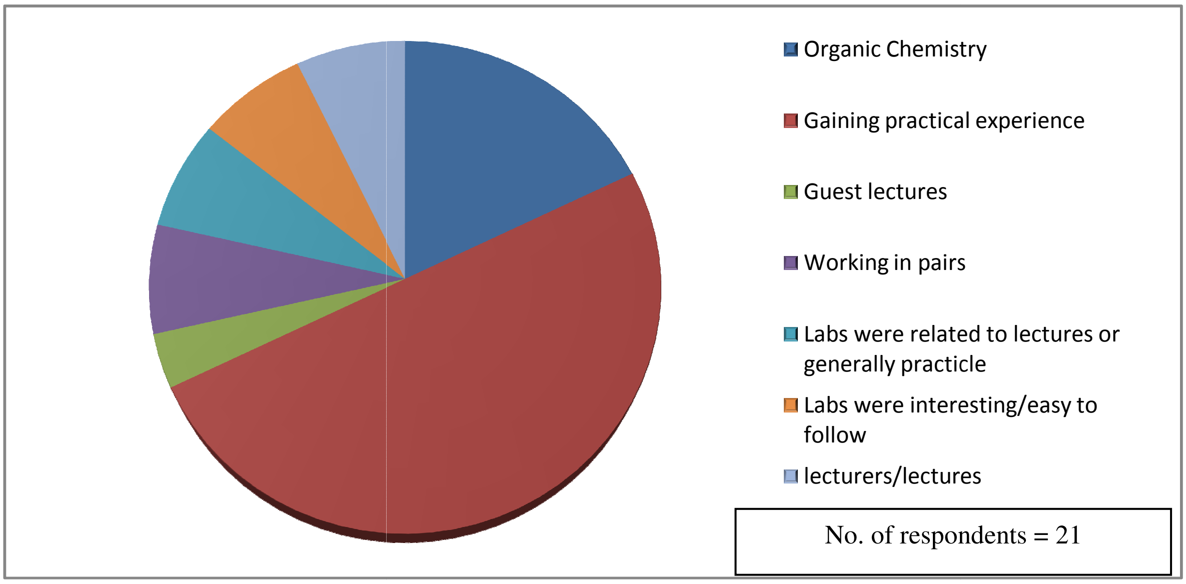


Figure 5 Student responses on the *Best Part* about Chemistry Practicals

The most significant *Worse Part* of Chemistry experiments reported by survey participants was to do with the reports/calculations (33%) as shown in Figure 6. Other responses that were noted to do with class sizes and class times are outside of our control but the response of standing too long was noted and lab stools were purchased for the first year lab and used when suitable. First year Science students have been reported to have difficulties with maths by Panther, Black & Larkins (2013) and in Ireland the majority of Third Level colleges have support systems in place to assist first year students who encounter problems. Qualifax, the National Learners database survey on third level education provide this information.

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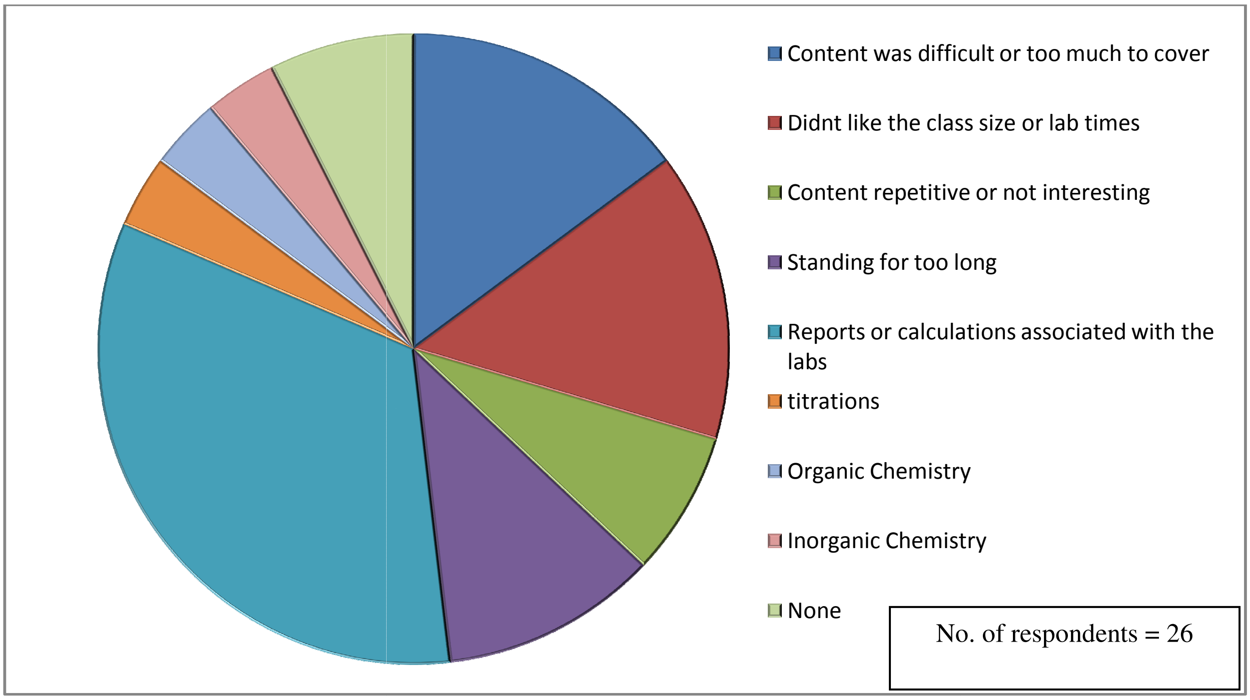

Figure 6 Student responses on the *Worst Part* about Chemistry Practicals

Conclusion

This survey does not purport to be all encompassing as the number of respondents is less than would be required for significant research work or generalisation. Much of the conclusions re-emphasised previous work on the subject (Johnstone, 2000; Seery, 2010). However, insights that can be gained from it are as follows:

- Students do enjoy gaining practical experience and they believe that the skills learned are useful to them in their undergraduate years.
- Students are suffering information overload in laboratory practical sessions. This is compounded by the fact that <50% read the instructions for the practical session prior to attending the lab. A possible method of improving the engagement of first years with their practical material is by the introduction of pre-laboratory questions. These could be only 1-4 short questions that would require that the student the look up the theory or at least read the procedure prior to attending class.

- Students are spending a large amount of time > 30 minutes on the laboratory write up. In hind sight, 2 additional survey response options here of >60 minutes and >90 minutes would have improved the value of this data. Invariably, the quality of the reports can vary dramatically and students can transcribe the introduction and method without considering the purpose of the experiment or what was achieved. Some of the reports do have questions relating to the topic that would require students to research the answers. The introduction of a laboratory workbook with pre-set spaces for data and answers could improve this.
- The results re-emphasise that maths and simple numerical ability is an issue for many students. In the free response sections in question 18, the calculations being difficult came up again for both Chemistry and Physics practicals.
- Overall, the content of the practicals is suitable for undergraduate science students but the pedagogy needs to be improved to engage the students more in the subject and make use of this valuable and expensive resource.

Review of Objectives of Laboratory Work and the Pedagogy Applied

Much has been discussed on the aims of laboratory work in general but from the perspective of first year chemistry courses I propose that the following objectives are keystones to chemistry education:

- ❖ Training in practical and behavioural skills for working in a laboratory
- ❖ Re-enforcing key concepts from lecture material
- ❖ Learning how to carry out basic experimental techniques in a safe manner
- ❖ Introduction to data processing and manipulation
- ❖ Developing observational skills and deduction

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This research demonstrates again how too much information causes a lack of understanding in the students' perception of what actually was taking place. It is well known that a small minority of students read the manual before entering the laboratory and when they do it is to use them as a "cookbook" to quickly find out what has to be done (see Hofstein & Lunetta 2004, p.40; Eilks & Byers, 2010, p.237). Based on this research, a review of experiments was undertaken. To compensate for the excessive time being spent on report write up, the students were supplied with a workbook along with the First year laboratory Manual. This workbook was pre-populated with templates for each experiment. The template included:

- Sections for results of weighing, titrations, or Calculations, Observations, Discussion and Conclusion
- Some practicals included leading questions to guide the students to report observations and conclusion and the rubric for the marking system was included

A concern was raised that the students would lack the skill of report writing. To compensate for this, as part of the general chemistry course, the students were tasked with a report or poster on a specified subject. Here they could develop the skills of report writing.

To attempt to make the students read the manual and workbook before the session, pre-laboratory questions pertaining to the experiment were included. These were worth between 10 -25% of the marks for that practical depending on the level of difficulty. They attempted to ask some questions that made the student read the manual to understand the topic as well as the purpose of the experiment.

With the introduction of modularisation, there appeared to be a reduction in linkages between lecture content and experiment. Organic and Inorganic lectures occurred each week for both semesters. It was noted that the practicals pertaining to physical chemistry occurred in the first semester with the lecture material taking up the latter half of the second semester. The lecture sequence and laboratories experiment were re-designed so that all general and analytical lectures with their respective laboratories were taught in semester 1, and all organic and physical chemistry was taught in semester 2.

One of the major issues with modification to first year practical sessions is the large number of supervisors and demonstrators that cover the session and, in order to communicate all changes, a pre populated answer book was developed. Also, a "suggestions" and "corrections" copy of both the lab manual and the workbook were made available to all staff and they were encouraged to include new suggestions for improvement. This was found to be very effective in maintaining communication between staff who might not often meet.
It is hoped that the pre-laboratory material can have the effect as demonstrated by other research. Johnson *et al.* (1994) performed a test on pre-lab work which demonstrated a 5% increase in marks and an 11 % increase in overall performance and that the students were far more positive about laboratories. Another survey is planned to determine if the changes made have had the desired effect by surveying students who have gone through the above changes to the laboratory programme.

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Appendix 1

This survey should take 10 minutes to complete.

Evaluation of First year Chemistry Practicals in preparation for future laboratory work

This survey is part of a project funded by the Learning, Teaching & Technology Centre, DIT. The questionnaire is completely confidential and anonymous. Please answer all questions truthfully and to the best of your ability.

1.	**What is your principal subject** Please circle	**Physics**	**Chemistry**	**Biology**	
2.	**Gender** Please circle	**male**		**female**	
3.	**Age** Please circle	**18-21**	**22-25**	**26-35**	**>36**
4.	Course and Stage **Please Circle**	**DT261-2 DT203-2 DT299-2 DT227-2**	**DT 235/2 DT 259/2 DT 260/2 DT 261/2 DT 757/2**	**DT261-3**	**DT203-4 DT299-4**
5.	On average how much time did you spent completing the lab write-up in first year?	<30 minutes		>30 minutes	
	In this section, please rate the following statements in relation to **your first year laboratory practicals**.	**Strongly agree**	**Somewhat agree**	**Somewhat disagree**	**Strongly disagree**
6.	The experiments improved my understanding of the subject from the lectures.	1	2	3	4
7.	I always understand the purpose of the experiment after completion.	1	2	3	4
8.	I always read the feedback on my lab reports.	1	2	3	4
9.	I never read the instructions prior to going into the laboratory.	1	2	3	4
10.	I was able to apply the work I learned in first year to laboratory work for future years.	1	2	3	4
11.	There was too much information given to know what was going on.	1	2	3	4
12.	The written instructions were easy to follow.	1	2	3	4

13.	The supervision was satisfactory.	1	2	3	4

	For the following types of practicals, please rate them under the following headings **Excellent = 1; Good = 2 Fair = 3 Poor = 4.**			
		Did you understand the purpose of experiment?	**Did you learn how to set up apparatus?**	**Did you understand the calculations?**
14.	**Physical Chemistry for example** Sand and Salt Recrystallisation Distillation of coffee Heats of neutralization Gas Constant			
15.	Qualitative analysis of unknown cations			
16.	**Organic Chemistry for example** Molecular Models 1& 2 Alkanes/ Alkenes Zwitterions/ alkanes/ alkenes Chemistry of alcohols Thin layer chromatography			
17.	**Analytical Chemistry for example** Burette/ pipette Titrations Gravimetric determination of Copper			
18.	Please name an experiment you completed in first year chemistry labs that you enjoyed doing?			
19.	Please name an experiment you completed in first year chemistry labs that you thought was a waste of time?			

	Please circle the following where you have undertaken first year Biology, Chemistry and/or Physics Practicals		
20.		What was the best part about them?	What was the worst part about them?
	Biology		
	Chemistry		
	Physics		

Additional comments and suggestions are encouraged

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Thank you for your time and support with this questionnaire

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