Paper

Promoting active learning through small group laboratory classes

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Abstract

Limitations of routine laboratory work are summarised and the importance of synergy, time and motivation to the promotion of meaningful learning is identified. A recent attempt to promote active learning through the introduction of student-led pre- and post-lab sessions into two environment-based group laboratory assignments is described. The innovation was evaluated through a student questionnaire and classroom observations and a number of advantages and disadvantages of the approach are identified.

Introduction

Modern undergraduate practical classes have their origins in the 1820s when Liebig introduced laboratories for general student use at the University of Giessen in Germany[1] and the first book to deal with laboratory technique, Michael Faraday's *Chemical Manipulations*[2] was published in the UK. Laboratory work quickly came to be regarded as an essential and major component of chemistry teaching. The Royal Society of Chemistry in the UK typically requires a minimum of 200 hours practical work for any course to be recognised as being of graduate status and many degree courses contain far more. Quantity has, however, never been a guarantee of quality and traditional university teaching methods have been increasingly questioned over the past twenty years. While major concern has focused on the ubiquitous didactic lecture, the value of much laboratory work has also been questioned, with concerns expressed not only about the learning experience[3, 4] but also about each of the following aspects.

(a) *Cost:* Laboratory work is expensive in resources, time and space; with the present restricted funding it is increasingly viewed as a luxury.[4, 5].

(b) *Health and Safety:* Recent legislation has greatly reduced the freedom that can be given to students in laboratories and the resulting restrictions may well reduce both pedagogical value and student motivation.[6, 7]

(c) *Employment opportunities for graduate chemists:* Although the importance of Chemistry continues to increase (it underpins the Life and Earth Sciences, both old and new) the need for traditional analytical chemists is decreasing. Increased automation of laboratory instruments has both changed the nature of the employment and reduced opportunities in many laboratories. While the skill of the analyst may still on occasion be critical, it is now common for the quality of the instrumentation to be the controlling factor in the work.[8]

(d) *The changing nature of the student population*: A decreasing percentage of students studying chemistry intend to become practising chemists. The development of good laboratory technique is thus of limited value for the majority of our students,[9] though it remains vital for those who do wish to go on to become professional chemists.

The idea of preparing the learner for laboratory activities is not new. Jenkins reported[10] that discussion and written tests were being used to introduce practical work in secondary schools at the beginning of the last century. While similar approaches may well have been used from time to time in higher education, it is only recently that the rationale for and the aims of such pre-lab exercises have been clearly enunciated.[11] The past five years have seen a general interest in improving learning through such pre-labs, and a number of innovative and productive computer packages have been described.[12, 13, 14] The use of post-labs to facilitate reflection and to promote the consolidation of learning would appear to be relatively new.[15, 16] However, such an approach is clearly consistent with current theories of learning and is likely to become more widely used in the future.[15, 17] The current study differs from earlier work in that the students were given control of both pre- and post-lab activities.

Although the value of much laboratory work can justifiably be questioned, one surely can't be a chemist (or even a chemically educated person) without a sound appreciation of the role experimentation plays in the development and practice of the discipline. It is equally vital for non-scientists to appreciate what can and what cannot be achieved through experimentation. Laboratory work obviously remains essential to the development of a range of practical skills; there is a limit to what can be achieved through computer simulations and video discs[18] and it is often asserted that practical work can help students to acquire knowledge and develop understanding of concepts, principles, models and theories.[19, 20] It is also suggested that it is through practical work that students can begin to understand what scientists do.[21, 22] After all, here we do have the active involvement of the learner. However, for meaningful learning to take place, it is the brain not just the hands that must be active. Unfortunately, effective thinking in the laboratory is often inhibited because of information overload in our limited working memory.[23] Although laboratories can provide a potentially rich learning environment, there does not appear to be any convincing evidence that routine laboratory work does in fact help students to understand concepts and theories.[24] However, where laboratory work is supported by the need for planning and outside reading, as in much project work, improved understanding may well occur.[25] Three factors, *synergy, time* and *motivation* can be seen as essential to the promotion of meaningful learning, although they rarely seem to be considered in the planning and implementation of practical programmes.

Synergy literally means working together, so that the whole is greater than the sum of the parts. Nowhere is this more important than in education, where everything that we learn has the potential to interpret, qualify, enhance and redefine a wide range of other things that we thought we already knew. Education isn't just about learning more, it also involves learning better, but it is only when new information is successfully related to what is already known that any meaningful learning will occur.[17] It is therefore important to ensure that what students are being required to do in laboratories is linked as well as possible both to the formal lecture programme and to the world in which they live. All too often students see laboratory work as unconnected to other aspects of their tuition and it is here that pre- and post–lab assignments can be particularly useful, both to identify and subsequently to consolidate the links to what is already known.

Thinking time is required to enable new information to be linked and interpreted.[26] Unfortunately, students seek to reduce the time they think about practical work to an absolute minimum. Laboratory instructions that enable students to follow a recipe to complete an experiment without even thinking about what they are doing thus militate against learning taking place.[23] However, appropriate pre- and post-laboratory tasks have the potential to promote more effective learning by increasing the time when students are required to be thinking about laboratory exercises.

Because learning is an active process, the learner must be motivated to make the effort to learn. Motivation is, however, an extremely complex issue. We need to distinguish between intrinsic or task-orientated motivation, which leads the learner to want to learn something for its own sake, and extrinsic or ego-orientated motivation, which leads the learner to learn something only to try and achieve some additional goal.[27] All too often students see laboratory work as a form of assessment and are motivated not by the opportunity to learn but only by the marks that may be obtained. To make matters worse, because they are required to do something different each time they go into a laboratory, our students rarely feel comfortable with what they are doing and tend to believe that they are poor practical workers. Thus, far from being motivated by practical work, many students actively dislike it and complain that it provides little reward in the way of marks for the time and effort that they are required to devote to it. Motivation is likely to be increased when students consider laboratory activities to be more relevant,[28, 29, 30] are given greater control over the process[30, 31, 32] or are permitted to work in small groups.[33, 34] The current study made use of all three of these factors

Despite all their apparent potential to promote learning, our expensive and time consuming laboratory classes usually fall well short of expectation.[35] If practical work is to continue to play a significant role in the education of chemists, and non-chemists studying chemistry as part of their courses, it is essential that it should provide a meaningful and positive learning experience. To achieve this it is surely necessary that students be encouraged to think far more about what they are going to do, about what they are doing, and about what they have done in practical classes. It is also important that they should enjoy doing it. To promote these aims, student-led pre- and post-lab sessions were recently introduced into two established laboratory assignments.

The Study

Student centered pre- and post-labs were introduced into two of the ten practical assignments associated with a second year module, *Environmental and Safety Issues,* taken by students on the B.Sc. (Hons) Applied Biochemical Sciences degree. All experiments were group based and all could have incorporated the innovation easily. The two chosen experiments, *Examination of a Natural Water Sample* and *Heavy Metal Analysis of Solid Samples,* were considered particularly suitable because students could be given responsibility for the collection of samples in these experiments. The water experiment required students to investigate a range of physicochemical parameters, i.e. appearance, odour, pH, conductivity, total dissolved solids and hardness. The heavy metal analysis required levels of lead and zinc to be determined by atomic absorption spectrometry. Although the metals to be analysed were specified, it is possible and probably desirable that in future the students themselves should decide which metals to investigate.

The week before carrying out either of these experiments, students in assigned groups of six or seven were required to discuss the factors they thought may influence the parameters they were to measure, agree what samples each student would obtain, and investigate and write a brief synopsis of their ideas as to how they expected the parameters to vary. They were thus being required to think about what they were going to do and to form a working hypothesis. This took place during the laboratory period and occupied about 30 minutes. The instructor provided no input at this stage and the students were free to choose their own samples. It is therefore fair to consider this to be a student led pre-lab. Water samples selected included samples from various locations on the River Lagan and samples from a range of lakes throughout Ulster, while solid samples included scrapings from the exhausts of motor vehicles using a range of fuels and dust sweepings from various locations.

Students were required to collect their samples and then carry out the analytical procedures during the next laboratory class. Standardisation of reagents and calibration of equipment, including any associated calculations, were shared by the group but all students were responsible for obtaining and investigating their own samples and for calculating their own results. The group was required to reconvene in a subsequent laboratory period to pool the results obtained and to consider how the experimental results compared with their earlier predictions. The group was asked to revise their earlier ideas in the light of the results obtained and to suggest two additional samples that they would now like to analyse to support or check their ideas. This process appeared to take less than 30 minutes, again there was no input from the instructor and so this can be considered to be a student led post-lab. Students were required to submit a report in their laboratory books on the analyses personally carried out and also to submit a brief separate report on the group project and any conclusions they felt could be drawn.

Evaluation

A student questionnaire was used to assess student reaction to the approach and this was supported by my own classroom observations. The questionnaire was in two parts. The first six questions asked students to evaluate aspects of the practical programme in terms of both understanding of what they were doing and their enjoyment of the laboratory sessions, using a six point Likert scale,[36] and the remaining eight questions were open response. The questionnaire, which was anonymous, was given out at the end of the laboratory session in week 9 of a twelve-week semester. By this time all students had completed eight practical assignments, including the two featuring the innovations, and a safety incident role-play / case study. One student agreed to collect and return completed forms; thirty forms from a class of thirty-eight were subsequently returned. The missing forms were accounted for by absentees and early leavers and there was no reason to believe that the returned forms were not representative. The questionnaire, with responses to the Likert scale questions, is in Table 1.

The vast majority of students (29) clearly indicated that they much preferred the approach used here to that normally encountered in laboratory sessions. One student indicated that he/she much preferred the usual approach (Q7). Nine students suggested that they believed understanding/learning was improved, ten suggested that team working and communication skills were improved and two suggested that their confidence was improved. One student stated that they had learned to deal with people who wanted to do everything themselves and wouldn’t listen to anyone else’s point of view (Q8). Five students suggested that working with smaller groups would be an improvement, as it had proved hard to get everyone to cooperate. Five recommended that students should choose their own groups from friends

Table 1. Student Opinions on Laboratory Exercises

Course: Environmental and Safety Issues

Please indicate, by ticking the appropriate box, how helpful you have found each of the following features with respect to (a) understanding and (b) enjoyment of laboratory exercises *(starting with **0** to indicate useless, rising to **5** where you would consider the feature indispensable).*

Q	**Features of the course**		**0**	**1**	**2**	**3**	**4**	**5**
1	Laboratory manual	(a)		1	1	7	14	7
		(b)		3	5	13	6	3
2	Working in groups	(a)		1	4	6	10	9
		(b)		1	3	2	7	17
3	Pre-lab discussion on sample selection	(a)		2	4	10	8	5
		(b)	1	4	5	13	4	2
4	Post-lab discussion on results obtained	(a)	1	3	4	7	9	6
		(b)	3	2	7	8	6	3
5	Pooling individual results	(a)	1	3	5	6	7	8
		(b)	2	5	2	10	8	3
6	Case study presentations	(a)			2	5	7	16
		(b)			2	6	5	17

7. How do you consider the general approach used in these practicals compares with normal laboratory sessions?
8. What do you believe you have gained by working in small groups?
9. What suggestions do you have for improving the working of the groups?
10. Which experiment did you find the most interesting? Why?
11. Which experiment did you find the least interesting? Why?
12. Do you have any general suggestions for improving these practical sessions?
13. How do you believe performance in these practicals should be assessed?
14. Any other comments you would like to add.

who could be relied on, while four suggested that there should be delegated tasks for each individual in the group (Q9).

Strong support was shown for the two pre-lab/post-lab experiments, with thirteen students naming the heavy metal analysis and nine identifying the natural water sample experiment as the one they found to be most interesting. However, no significant reasons were given for these choices. Only one student identified the session in the sewage laboratory as the most interesting, explaining that this experiment had enabled a question posed at an interview for an industrial placement position to be well answered (Q10). The sewage laboratory experiment was considered the least interesting session by the largest number of students (9), with a lack of direct student involvement being given by a number of people as the reason for this choice (Q11).

Students suggested that the practical sessions would be improved if they were required to do fewer experiments and if the demonstrators knew more about what they were doing. Although this was referred to in only three of the returned questionnaires, criticism of the performance of the demonstrators is a cause for concern. A recent report suggests that active learning strategies can be undermined where demonstrators are either unfamiliar with or do not successfully fulfill their required roles.[37] Unfortunately, as no problems were apparent while the laboratory course was in progress and as the questionnaires were anonymous, the reasons for this criticism are at present unclear. It is, however, the intention to observe this interface more closely in future. Some students also suggested that they had found the pre-lab sessions particularly useful and that wider use of such pre-labs would be beneficial (Q12), much as reported previously.[11] Attendance, contribution, understanding and accuracy were suggested in various combinations as the recommended basis for assessment (Q13). No significant comments were made under Q14.

Students appeared to settle quickly into their assigned groups, with one individual usually taking on the role of coordinator. Usually this individual was also the dominant contributor to the group's practical activities, though in two groups the coordinator seemed to adopt the role of 'foreman' and left most of the practical work to others. Following the pre-lab session students did appear, at least to my subjective eye, to have a greater sense of understanding and purpose about their activities. A few incidents of friction were observed between individuals in the groups, but these were rare. Students clearly discussed the tasks within the groups and thought about what they were doing. It was quite common for students to check values with each other to see if their earlier ideas were being borne out. However, once the group had accepted an idea, there was little evidence of any attempt to improve on this. This is consistent with the suggestions by Garratt[38] that students need to become familiar with a new learning approach before they can be expected to engage with it fully.

Conclusions and Reflections

This study illustrates the way in which an inquiry-type dimension can be incorporated into what are essentially expository or recipe-following types of exercise.[39] While the analyses described are likely to form part of the laboratory programme for a wide range of degree schemes, the present approach should enable students to appreciate why it can be important to continue to carry out such analyses. Analyses may be necessary for example to show compliance with legal standards or to establish spatial and/or temporal variations of the parameters. In a typical experiment a group of students analysed the lead and zinc content of dust sweepings from a garage floor, a number of domestic backyards from different locations in the Belfast area and a farmyard. The pre-lab discussion led to the suggestion that heavy metal levels were likely to be highest for the garage sample while levels for the other samples should decrease as sampling moves to more rural locations. However, the subsequent analyses showed that levels in the sample obtained from the farmyard were considerably higher for both metals than for any of the other samples. The post-lab discussion focused on possible activities in farmyards and recommended that analyses should be carried out on samples from other farmyards. The facilitation of discussion in peer groups through the pre- and post-lab sessions encourages deeper thinking about experiments before they are carried out and deeper reflection on the results than is usually found with recipe-following procedures. In addition, by giving students control of the process and the freedom to make choices, interest and motivation are likely to be increased.[30] Such experiments would appear likely to promote what Burmester called[40] *scientific thinking*, as well as team working and time and task management skills.

Convenience of sampling was undoubtedly a major variable in the procedure discussed. There is little doubt that students could have been directed to collect an intrinsically more interesting set of samples or that students would welcome such help. On balance, however, it seems very likely that giving students more responsibility for the process produces a better learning outcome. Although ideas were discussed in the post-lab sessions, it was clear that students were looking for early resolution; once an acceptable idea had been tabled there appeared to be no interest in looking for alternatives or in trying to improve on it. This then is clearly an area for future improvement. We have no plans to move back towards a more teacher centred procedure and have decided that in future groups will be required to make an oral presentation of their results and ideas to the class. Each presentation will be followed by a general discussion of alternative ideas.

Student questionnaires, particularly those dependent on quantitative indicators like the Likert scale questions used here, must be interpreted with care if unwarranted conclusions are not to be drawn.[26] Nonetheless, some general conclusions are probably justified. Although a large majority of students expressed support for the arrangements, a small number were clearly unhappy with key aspects of this laboratory programme. This is consistent with the suggestion of Bodner[41] that any significant classroom intervention is likely to be harmful to some students even though others will benefit. There was a significant variation between student opinion of effectiveness with respect to understanding and with respect to enjoyment for all aspects except the Case Study Presentation (Q6). This is important, because while cognitive and affective factors are not likely to be independent of each other, students clearly felt able to distinguish between them here. In general, students appear to feel that working in small groups helped understanding and, in particular, their enjoyment of the laboratory exercises (Q2). On the other hand, enjoyment and to a lesser extent understanding associated with the pre-lab discussion, the pooling of results and the post-lab discussion were rated much lower. Most of the problems identified in the free response section clearly related to problems with group dynamics. It seems likely that, while most students enjoy the social interaction of group work, many are not yet functioning efficiently as team members

The responses to the questionnaire strongly suggest that interest increases as students are given more control over their experiments. Twenty-two out of thirty respondents considered one of the two innovative experiments to be most interesting, while the afternoon in the *Sewage Laboratory,* which consisted largely of demonstrations by a technician, was considered the least interesting by the most students. Interestingly, of the six aspects assessed through the Likert scale questions, the highest rating for enjoyment and understanding was expressed for the Case Study Presentation. This involved groups representing the interests of various parties involved in a serious laboratory accident, thus generating direct competition between the groups. This appeared to result in high levels of commitment to, and cohesion within, the group. A positive effect of controversy on the promotion of learning has previously been reported.[42]

There are also, however, a number of disadvantages associated with such experiments. Firstly, they are time consuming and there is a need to balance the perceived benefits of enriched learning from a particular task with the desirability of increasing the range of experimental work experienced.[43] One experiment on exhaust gas analysis was dropped and the sharing of tasks, such as calibration and standardisation, created the time for the pre- and post-lab discussions in the present case. Assessment is a more complex problem and it is likely to be both difficult and time consuming to differentiate reliably between group members. Currently each student is assessed independently for his/her individual sample analysis and a further mark common to the group is awarded on the basis of the pooled results and the pre- and post-lab reports. Although much-valued group working skills were being developed, there were clear examples of conflict within some groups and not all students appeared comfortable with this approach. Many students suggested that some of their peers were not pulling their weight, although this was clearly an oversimplification. There are many possible reasons for lack of cohesion within a group and it will be important to understand exactly why individuals are not working efficiently in such situations if we are to help them improve.

Expository type laboratory activities will continue to be needed to nurture the development of experimental technique and reliability with respect to data collection. Such experiments, however, do little to promote interest, are ineffective in promoting the use of higher order cognitive skills, and provide an unrealistic portrayal of scientific experimentation. The introduction of an inquiry-type dimension into an experiment enables a *learning cycle*[33, 39] approach to be taken. The results reported here suggest that such an approach is likely, in general, to improve both the learning experience and student motivation in laboratories. While not all experiments may be suited to such modification, several recent publications describe how expository procedures can be easily modified to introduce an inquiry dimension into laboratory activities. There is clearly a case for introducing such experiments into the early years of university courses before students become disenchanted with laboratory work.[16, 32, 44, 45]

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