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INTEGRATING LEARNING AND ASSESSMENT IN LABORATORY WORK

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ABSTRACT: One of the requirements of employees by laboratory managers is that they have good practical skills and thus the teaching of these skills in an undergraduate course is essential. Traditionally laboratory work has been closely tied to individual lecture courses in order to support theory. At The Robert Gordon University, considerable care has been taken to devise a laboratory programme, which follows a progression of assessment and learning strategies. We have created separate laboratory modules, which are suitable for development of various transferable skills (e.g. written and oral communication, numeracy, IT, organisational skills including time management) as well as integration and application of material covered in other parts of the course. In this paper we describe our programme of laboratory work and assessment, and we discuss the problems and issues raised from the teaching of laboratory work. Traditionally laboratory work has only been assessed by laboratory reports but here we describe alternative forms of assessment and the possible benefits and outcomes from such an approach. [*Chem. Educ. Res. Pract.*: 2003, 4, 67-75]

KEY WORDS: *laboratory skills; transferable skills; assessment.*

INTRODUCTION

The teaching of laboratory work and hence laboratory skills has always been an integral part of any science-based course throughout the twentieth century. However its practical classes go back to the nineteenth century (Lagowski, 2000). In 1827 the famous scientist Michael Faraday published a book on laboratory techniques (Faraday, 1827). Recently both the Chemistry Benchmarking Document (Bulletin of QAA, 1998) and the Dearing Report (Dearing, 1997) specifically mention the necessity to develop “subject specific skills such as laboratory skills”.

Why do we teach these skills? Several reasons are usually given:

- they enhance the student’s learning of fundamental concepts;
- they give the students a hands-on approach thus enhancing their manipulative and observational skills;
- they allow students to see chemical reactions;
- they are enjoyable;
- they are fundamental to the study of chemistry;
- many undergraduates receive employment where these important skills are used.

For an overview on laboratory work we would refer the reader to the review by Johnstone and Al-Shuali (2001) and the introduction in the paper on group work by Byers (2002), whilst Hodson (2001) discusses the case for rethinking our approach to practical work.

The purpose of this paper is to discuss assessment practices for the laboratory modules, and consequently the transferable skills gained by the students during this activity, given that practical work is an essential part of the curriculum.

It is more usual on traditional courses for the laboratory classes to be included within the subject modules. However, at *The Robert Gordon University*, we have developed separate laboratory modules. There is a danger when courses become modularised that the learning becomes “compartmentalised”, and that students tick off the modules as they pass them, failing to see or look for a connection between them and move on to the new module (Rust, 2002). Rust further suggests that modules have too much summative assessment and insufficient formative assessments due to lack of time. The rationale behind the move to separate laboratory modules was that we could more easily achieve the development of practical skills by devising a smooth transition from year to year. These modules would provide a gradual progression of developing the necessary laboratory skills and competencies within the context of the laboratory. In addition, we hoped that as the mode of assessment changed from year to year, the students would also develop and improve some or all of the transferable skills identified at the beginning of this paper.

It has been said by one of the UK Examination Boards that, “*assessment can be used as a means of selection, as a way of diagnosing strengths and weaknesses, and to assist with evaluation. Its most important use, though, is for judging performance in education and training so that qualifications may be awarded*” [Scottish Vocational Council (SCOTVEC), 1993]. As an Examination Board SCOTVEC use assessment as a means of awarding qualifications. In a later publication by the Scottish Qualifications Authority, which succeeded SCOTVEC the principles of assessment are stated as being “*valid, reliable and practicable*” (Scottish Qualifications Authority, 1999). Over the last couple of decades, there have been changes made to assessment practices. Rather than just the selection and certification process, there is an increasing emphasis on learning from assessment for the learners, and for the teachers as well, on feedback to the learners by the teachers, and on a move from dependence on one main method of assessment to a variety of assessment methods. There has also been a move away from assessment by teaching staff and more involvement of self and peer assessment (Holroyd, 2000). We feel that this latter role of assessment is of equal importance to that of awarding qualifications.

All the modules on our degree courses, apart from the laboratory modules, are assessed by end of semester examination and by one or two pieces of coursework, which counts towards the final grade or mark. The laboratory modules are assessed entirely by coursework, by using a range of different assessment methods, e.g. keeping laboratory diaries, oral presentations, writing formal reports. In addition to being an alternative method of assessment, we hope that these methods will help to develop the key skills such as communication (e.g. writing formal reports, giving oral presentations, numeracy (calculations), and the use of information technology (*IT*, e.g. searching databases, drawing graphs), as recommended by the Dearing Report (Dearing, 1997). As part of the assessment strategy, each student must keep a laboratory diary, which must be completed during the laboratory session not outside the laboratory at a later time. This helps to ensure that there is no loss of data and that the laboratory diary is the work of the student. Whilst part of the role of colleges and universities has been to prepare students for employment, they can no longer look forward to secure employment for the rest of their lives. Thus graduates need transferable skills, such as good presentation skills and communication skills, which will

enable them to move into different careers within a lifetime (Hodgkinson, 1996). The case for teaching these skills was strongly put forward by Bailey at the Nyholm Symposium (York, 21 February 2001) (Bailey, 2001).

THE PROGRAMME

The programme consists of one module per semester for each of the four years (8 modules in total, which is approximately 800 hours of student contact over 4 years.) The laboratory programme is designed so that the students may develop a range of skills, such as using and handling essential equipment, and chemical and biological substances, good written and oral communication skills, IT skills and numeracy. All these skills are needed, to a lesser or greater extent for the outside world of employment. Some of the exercises are designed to provide exposure to new apparatus or experimental techniques while others, are designed to develop and improve problem-solving skills. In order to try and improve the latter open-ended exercises are given, e.g. synthesis of organic compounds, where only the starting material is given, or methods of analysis must be decided upon such as determination of heavy metal content of soil. The modules are free-standing rather than being part of a subject module but great care has been taken to ensure that the practical work does relate to and reflect the content of the other modules as well as provide development of practical skills. By looking at and planning the content of each of the laboratory module descriptors it is possible to get a progression not only of the practical skills but also of the transferable skills. This then helps to support the learning of the content of the other modules. Each experiment, however, has sufficient background information given in the introduction to ensure that the experiment can be carried out on the specified day, even if this part of the content has yet to be covered in the lecture module. The students therefore receive the concepts and ideas more than once, which is an aid to deep learning rather than surface learning in the particular subject. This allows the students a hand-on approach for the analytical instruments, because these experiments have to be run as a "circus" as we have insufficient equipment for all the students to do the experiment on the same day (e.g. high performance liquid chromatography, atomic adsorption spectrophotometry, gas liquid chromatography).

Year 1 concentrates on learning basic skills and techniques such as titrimetric analysis and purification techniques of organic compounds. A great deal of laboratory work has been described by Meester and Maskill (1993), as "controlled experiments". i.e. the answer is known in advance. It has been argued that these experiments which involve recipes should be regarded as "exercises" (Bennett & O'Neal, 1998). At the end of year one, an exercise to analyse common household products is completed. We have implemented this task to help consolidate the practical skills developed during year one, and to introduce students to some of the skills involved in carrying out analytical investigations, such as experimental planning and design (Hunter, Wardell, & Wilkins, 2000).

Year 2 develops analytical chemistry and related technical skills associated with particular analytical instruments, for instance: infrared spectrophotometry, ultraviolet-visible spectrophotometry, atomic adsorption spectrophotometry, gas liquid chromatography. Other experiments related to preparation and purification of inorganic and organic compounds are also undertaken. The exercises are designed to develop analytical and technical skills relating to manipulation and purification of inorganic and organic chemicals. An important element of the course throughout all years is to develop practical skills and work practices appropriate to an experimental scientist.

In year 3 these skills are further developed by the use of more open-ended extended

experiments, group exercises and mini projects in organic, and inorganic as well as analytical chemistry, for instance: “developing the analysis of analgesic Aspirin as a project for 6th year secondary school pupils”; “the synthesis and characterisation of 1-phenylcyclohexene from cyclohexanol”. We distinguish between mini projects and projects by time scale. Mini projects are projects, which can achieve some results within a short space of time such as a few weeks. The extended experiments fulfil two functions: firstly to build on the core techniques by introducing a variety of applications and secondly to give the students the opportunity to develop time and task management skills. However, it is difficult to assess these particular skills. Observation of the student might be one way, but at present our assessment methods are based on the completed task. Some alternative methods of assessing the higher-order cognitive skills (HOCS) are described by Zoller (2000, 2001).

In the final year, which leads to the award of BSc (Hons), the students must undertake a substantial individual assignment - the Honours Project. Examples: “synthesis and binding studies of new anti-cancer agents”, “base oil recycling oil tools”. The project work is a student-led activity involving laboratory work and literature surveys. Six weeks full time are allocated for this activity.

A particularly important skill, which is necessary for the professional chemist to develop, is the “*accurate recording of data and decisions*” (Mason, 1998). We, therefore, ask each student to keep a laboratory diary, in which all notes about procedure, results, treatment of results, calculations, observations and conclusions must be recorded during the laboratory session. It is not acceptable for the student to scribble results down on odd scraps of paper! A diary must be kept for each year and submitted for marking at the appropriate time. This forms part of the assessment procedure later described.

ASSESSMENT PROCEDURES

When assessing laboratory work it is essential that for effective assessment the assessment must match the desired learning outcomes (see below for year one learning outcomes). To ensure that assessors are able to give a clear and consistent judgement and that the students are able to complete the assessment task, criteria must be clearly stated. It is also important that the assessment is fair and reliable and that the feedback provided must be helpful and timely. It must be remembered that the purpose of assessment is not only to rank the performance of students and to allow them to proceed to the next stage of their course, but it is there “*to improve their learning*” (Brown, 2002)

In year 1 the laboratory work is largely prescriptive exercises. The learning outcomes, described in the module descriptor for year 1, are:

1. carry out prescribed experiments accurately and safely;
2. record experimental observations and results in a meaningful and accurate manner;
3. perform appropriate calculations on experimental results;
4. estimate errors and uncertainties;
5. draw appropriate conclusions from the results obtained.

In year 1 we use a traditional approach to assess the laboratory work. The assessment is that of written laboratory reports, which are written up in the diary. At the start of the first laboratory module, students are given examples of laboratory reports so that they can see the style and format we expect. These reports are marked weekly, usually by giving a grade or mark, to ensure that the right format and standards that we expect are maintained. This is a very time-consuming and burdensome task for staff and students, but a very necessary one. It can often be seen, however, to be an over assessment of the students’ work, yet we feel it is

the best way to give students helpful feedback. This feedback is given both by written comments and by verbal comments to the student during the next timetabled laboratory class. We have not yet tried any alternatives to this approach but an interesting and less time-consuming idea for generating feedback for large groups of students has been developed by Denton (2001) using Microsoft Excel and Word. The first learning outcome is the hardest to assess as outcomes 2-5 can be recorded in the laboratory reports but it is difficult to assess the practical skill required of outcome 1. We have not yet found a satisfactory formal way to assess this outcome, yet we believe that the learners do carry out their practical exercises safely and accurately because, with a ratio of two staff to a maximum of 30 students, they are well observed during their laboratory time. The overall grade given for the module by the staff marking the laboratory diaries is governed by the University generic grading scheme. The definitions of the grades are:

| | |
|---------------------------------------|---|
| Excellent (Outstanding performance) | 6 |
| Commendable (Meritorious Performance) | 5 |
| Good (Competent Performance) | 4 |
| Satisfactory (Adequate Performance) | 3 |
| Threshold (Borderline Fail) | 2 |
| Fail | 1 |
| non-submission | 0 |

This grade encompasses the outcomes 2-5 of the module.

In years 2 and 3, there is an additional outcome which states: “be able to communicate the results and conclusions of given experiments”, and thus we have changed from the traditional approach of using laboratory reports as a means of assessment to using a wider range of assessment strategies. These include inspection and marking of laboratory diaries and an oral assessment. During the oral assessment the students have access to their diaries but must be able to answer questions about the practicals. The practicals to be discussed are selected by the member of staff conducting the oral assessment. Questions are not pre-set by the staff, as it will depend on the initial answers. Typically we would begin by asking the students to explain what the aims of the experiment were, had they achieved their aims, what difficulties did they incur, what errors might have occurred. We would look at their calculations and graphs. We are trying to ascertain whether the student has understood the practical work that they carried out. An example of the assessment sheet is given below. This is not undertaken weekly as in the first year, but instead it is done in three or four week blocks. Thus feedback is given at the time of the oral assessment and advice to the students on how to improve their lab diaries can be given on a one-to-one basis. A third form of assessment is to write a full formal report on a given experiment. The member of staff, not the student, selects the experiment, which is to be written up as a formal report. This report must be submitted in a word-processed format. Written reports and oral presentations also assess group exercises. Here the oral presentation is more formal than the assessment of laboratory diaries as the students must prepare a short presentation to give to the staff. See example of assessment sheet below.

In addition students are also assessed on their general professional conduct and initiative in open-ended exercises and projects. To help ensure consistency of assessment marks between staff, guidelines and proformas (see Figure 1) are used extensively, and students are fully briefed on the various aspects of assessment procedures. Thus individual student grades are built up from this cumulative assessment record.

| BSc 2 Laboratory Assessments | | BSc 2 Laboratory Assessments | |
|--|--------------|---|--------------|
| Guidelines for Staff | | Guidelines for Staff | |
| Lab Diary Inspection The following guidelines are to be used for assessing the Laboratory Diary | | Oral Presentation The following guidelines are to be used for assessing the Oral Presentation | |
| Criteria | Grade | Criteria | Grade |
| Is the report properly headed and dated? Are you able to follow what was done and why? Are all the entries made? Are the folder entries cross-referenced? | | Have oral skills been exhibited in presentation? Has the presentation summarised the essentials of the experiment? Has the presentation been logically developed? | |
| On the basis of a random question (or two) did the student exhibit that he/she could understand the report? | | Have the data and results been properly discussed? Have the correct conclusions been presented? | |
| Final Grade | | Final grade | |

FIGURE 1. *Examples of Proformas.*

By using this learning and assessment strategy over the three years from year 1 to year 3, students are able to develop their transferable skills such as written and oral skills. Whilst a traditional approach would still see the development of practical skills the only form of assessment usually undertaken in that approach is the written laboratory record. Our programme includes a large variety of exercises and activities such as open-ended experiments, group work which is student designed and led, mini-projects and it also uses a several different modes of assessment such as interviews, oral presentations as already described. Our students benefit from the many different forms of assessment which help them to develop better oral communication skills which would not be achieved by writing laboratory reports.

The culmination of the laboratory programme is in year 4 with a substantial individual assignment (the Honours Project). In this double module, students demonstrate their initiative and problem-solving skills whilst carrying out the project. Assessment methods for this part of the laboratory programme are by interviews, a formal written report and by an oral presentation by the student. About half way through the time allowed for the project, the students must produce a draft introductory chapter for the final report, covering background knowledge and literature survey. The student then has an interview with the internal assessor to discuss this draft chapter. From the interview and the draft report the project assessor is able to ascertain how the student is progressing. At the end of the project not only must the student write a report but also he/she must give a short oral presentation using Microsoft "Power Point". Two members of staff mark each oral presentation and an additional member of staff as well as the supervisor marks the project report. Again proformas are used and marks must be agreed between the two assessors. The overall mark is made up from 25% from their supervisor based on discussions throughout the project and their final report, 50% from their assessor based on the interview, draft chapter and their final report and 25% on their oral presentation. Criteria devised for the oral presentation are divided into three sections:

1. Does the presentation show clearly the following?
 - Title, names of student and supervisor, background, aims and method, results and interpretation of results.
2. Is the Display effective?
 - In terms of layout, good use of text and graphics.
3. In the presentation is it clear that the student
 - Is able to fill in detail omitted from poster?
 - Understands the scientific content of the information presented?
 - Is able to sustain a discussion and present logical arguments orally, making appropriate reference to the presentation?

Are we however actually assessing laboratory skills by this method? Perhaps one criticism of this assessment programme and of many other programmes within universities and colleges would be that assessment of laboratory skills by these methods is still one step removed from assessing the practical skills because only the recorded results are assessed and it rarely assesses the higher-order cognitive skills. Accuracy and errors are therefore also only assessed by looking at the results. For most experiments perhaps this is sufficient, but if we were truly assessing practical laboratory skills there should be an element in the assessment procedure where the student is observed while performing the experiment by the member of staff using a check list of key skills. The methods of assessment that we are using rely very much on the recording and manipulation of results by the students and the grade awarded is a reflection of this.

BENEFITS

Feedback from students is obtained through regular formal questionnaires and discussion at student/staff liaison group meetings. The overall impression staff obtain from the student appraisal of our laboratory programme is that they enjoy the laboratory sessions, where the approach to learning is less formal and they are motivated by these learning experiences. In particular, the students have commented that the less prescriptive exercises are refreshingly unpredictable and enjoyable. In the past we have received comments such as “*good class, good practicals*”. Students interviewed about the third year mini-project have made the following comments:

- “*good module and enjoyable*”;
- “*it gave us a chance to develop project planning*”;
- “*as we were studying for the applied chemistry with management degree, we were able to chose a project which allowed us to develop and study new technical skills, which we hadn’t encountered before.*”

Our courses undergo an annual course appraisal, part of which constitutes a course questionnaire, which is devised by one of our University departments, where the students must rate each module on a scale 1 to 5. 1=Excellent, 2=Good, 3= Satisfactory, 4=Poor, and 5=Very Poor. The average is then calculated. The laboratory modules consistently received one of the best scores of 1.9 - 2.0

The main benefits to the students from this programme of learning and assessment are not only the acquisition of necessary technical skills required by professional scientists, but also competence in recording, processing, and reviewing data, development of the transferable skills of report writing, oral presentations, group work, project management, information retrieval, and IT skills. We believe that it also helps to develop their problem-

solving skills. Students show a steady transition of their writing skills from the shorter formal reports required in year one through the longer and more substantial reports of year two and the mini-project reports of year three culminating in the Honours Project Report of year 4. The lab diary interviews and the use of oral presentations as well as written reports also helps students with special needs such as dyslexia who in the past might have been marked down because they find written work more difficult. Now they have a chance to achieve good grades by the oral assessments.

Whilst we have no formal feedback questionnaires to prove that this assessment programme has improved the transferable and technical skills of our students the verbal feedback from local employers is that our graduates are well able to take their place in the workforce and furthermore they have good communication skills, particularly presentation skills, and good IT skills.

In conclusion the progression from simple investigative procedures to lengthy and more detailed Honours project using a variety of assessment strategies makes for a rewarding, enjoyable and worthwhile experience for our students.

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