[O6] The Oxford integrated laboratory course in chemistry

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Keywords: chemistry practical course, undergraduate, integrated experiments

Introduction

The chemistry undergraduate degree program at Oxford is well regarded internationally, academically challenging, and seen as an attractive option by large numbers of students, yet in some respects, particularly in the syllabus that it follows, it could be considered too traditional in nature. Nowhere is this more evident than in the practical course, in which the emphasis is largely on illustrating the principles of chemistry and its logical foundations. This concentration on core chemistry is a reflection of a correlation of the practical course with lectures, but such a linkage carries with it the danger that other more modern – and perhaps more exciting – aspects of experimental chemistry might be sidelined or shunted out of the course altogether.

The entire undergraduate chemistry course at Oxford is currently under review and we have taken the opportunity to commit to a radical change in direction in experimental chemistry, whilst maintaining the emphasis on an academically challenging syllabus. This paper and the associated talk outline our plans to completely restructure and revitalize the practical course. We discuss the limitations of the current course and sketch out the directions in which we wish to take the new course. There are cogent reasons why a new approach to practical chemistry is worth considering; this paper outlines the approach we are taking and the challenges any new course faces.

Limitations of the current practical course

The undergraduate practical course at Oxford is fragmented, both physically and academically. It is housed in six separate laboratories, which are divided among three buildings, together with a dedicated computing laboratory housed in a fourth building. The laboratories themselves vary in the degree to which they are suited to undergraduate work, and their physical separation effectively prevents interaction between the different parts of the course, for example ruling out experiments in which students synthesize a sample in one laboratory and analyze it in another.

In a seven million pound refurbishment program now underway, Oxford University is relocating these six laboratories into one large area in a separate building, currently occupied by another science department. The new space will be flexibly divided into several contiguous laboratories, all of which will have ready access to separate dedicated computing and instrument areas.

In designing the physical layout of this new area, and taking into account the current review of chemistry, we have considered whether it is best to retain the present traditional division of the course along inorganic, organic and physical (IOP) lines, or whether alternatives are worth exploring, since a move away from an IOP course would have implications for the design of the refurbished laboratory space. Any reorganization of the practical course must take account of the review of the lecture course, which is likely to largely remove the main IOP boundaries. We have therefore decided to mirror the anticipated changes in the lecture course, and develop a highly integrated experimental course in which the IOP boundaries will be blurred, or even completely removed.

Why change?

The common model for the chemistry degree in western Universities, both in lecture courses and practical work, is to divide topics into discrete IOP segments. This is the model that has been in place for many years at Oxford. However, widespread adoption does not indicate that this is the only possible model; indeed, this approach suffers from a number of disadvantages.

A practical course divided along IOP lines does little to demonstrate to students the interdisciplinary nature of science. The boundaries between scientific disciplines are increasingly fuzzy and the most fertile areas of scientific research often lie at these boundaries. It is academically valuable to reflect this in the practical course and in addition students often find experiments that lie just outside the mainstream areas of chemistry particularly intriguing. Lecture courses in many Universities now implicitly recognize that the barriers between different areas of chemistry are to some degree artificial. If the role of the practical course is to illustrate and amplify lecture material, dissolving barriers in the lecture course should prompt similar action in the practical course.

Science education is expensive, so we are hoping that an integrated course will also be more cost-effective. Different courses use similar equipment; the same spectrometer that is used to assess the quality of organic products could also play a part in the analytical or physical chemistry courses, but at present, our division of experimental work across multiple sites means that sharing of equipment is difficult to timetable and there is pressure on courses to meet their own needs by duplicating equipment held in other laboratories. By bringing the teaching of five hundred students into a single laboratory complex, sharing of equipment is far more straightforward.

Finally, and perhaps most importantly, student motivation is a key factor in the redesign. Increasing both the variety in the course and introducing a more open-ended approach to experimental work will provide students with a sense of investigative freedom. We believe this will vividly contrast with the disinterested attitude that students may have when they are required to repeat experiments whose outcome is known or can be predicted before the experiment even begins.

What are the plans?

The planning process for the new practical course has the following goals:

1. *Bring together the labs physically so that sharing of equipment is simple and routine.*

2. *Divide the course into theme-based segments such as synthesis and experimental methods rather than topic areas such as organic and physical.*

3. *Create an introductory course to run alongside the lecture course in the first half-term of the first year*. In the first year lecture course, early lectures will focus on

chemical principles and will help to bridge the knowledge gap between school and University. The new practical course will have the same goals and will illustrate and reinforce this lecture course, simultaneously filling in some of the practical skills gaps remaining from A-level.

4. *Offer realistic opportunities for every student to engage in open-ended project work, as a taster for the year of research to come in the fourth year*. Students spend the entire fourth year at Oxford as a member of a research group. Many groups work on cross-disciplinary topics and we wish to give students a taster of the types of work they will be able to engage in during that final year.

5. *Integrate experimental chemistry with computer methods*. Although Oxford has particular strengths in computational chemistry, students commonly view computer methods as a subject set apart from the rest of the practical course. The deep integration of computers into chemistry at the research level is not necessarily apparent to undergraduates, so we aim to thoroughly integrate computer use into the practical course. The key here will be to encourage the perception of computers as tools, like spectrometers or rotary evaporators, to be regarded as objects that slot naturally into practical work whenever they might be of value. Instructions for experiments will of course be available to students online, together with safety information, details of experimental technique, video clips and similar material, but we aim to embed computers much more thoroughly. For example, experiments in photoelectron spectroscopy probe molecular orbital energies directly; we would expect students to follow experimental work with an investigation of computational MO methods without being specifically required to do so, in fact without this option even being suggested in the experiment instructions. Column chromatography is well suited to illustration through computer simulation, but a deeper understanding of the process can be gained through computer investigations into solids, surfaces, adsorption, the structures of zeolites and resins. We aim to develop an expectation amongst students that this sort of computational investigation is the natural way to proceed, not something that is done because the instructions for the experiment require it.

What has been done so far?

An informal survey some years ago confirmed that substantial overlap exists between the practical courses in different UK universities, an observation that will surprise few chemistry faculty. That experiments on the gas phase infrared spectrum of hydrogen chloride, or the visible spectrum of iodine vapour, appear in many courses reflects a collective judgment of those in charge on the value of such experiments. As we have concluded that an integrated course is an attractive option, we were hopeful that some universities would already have integrated courses in operation.

The reality is very different. Three Oxford summer students contacted chemistry departments in universities in the USA, Canada, the UK, Europe, Australia and elsewhere, gathering information on course content and approach. Many universities commented how attractive they felt the integrated approach to be and would be interested in the final outcome, but few had much to offer. We are therefore starting with the aim not of modifying what is already in operation at other Universities, but with the development of a fresh course essentially from scratch, while taking advantage of the experiences of others where possible.

Implementation

The final course will be some two years in construction, but its elements are becoming clear:

1. 1st year introductory course. The first part of the Introductory practical course will be closely linked to the lecture course which provides an integrated view of the chemistry to come. There will be no division into IOP sections in either lectures or laboratories, and there will be substantial use of group teaching in practical work with pre-labs and post-labs

2. The remainder of the 1st year practical course will focus on experimental techniques, particularly in areas such as vacuum methods or error analysis which are widely applicable. The reduction in the quantity of practical work at A-level has created difficulties for University chemistry departments; students now arrive at university less well prepared, so we feel that a course in techniques is an appropriate first step in the main section of the practical course. It is a little ambitious to consider project work at this stage, but we nevertheless are planning to include open-ended experiments, since one of our key aims is to encourage students to think in a scientific and enquiring fashion. For example, in the first year experiment on errors students will at times not be told what measurements to take, how to take them, or what the errors might be due to.

These techniques experiments will cover experimental error and the preparation of solutions and standards, vacuum methods, the principles of optics, separation methods and other topics. Though illustrated with examples from specific parts of chemistry, these will be taught as applications of chemistry, rather than the means to purify an organic sample, or carry out a specific vacuum-line synthesis. Even at this early stage there will be a focus on group work, on experiment design, and on exercises that depart substantially from traditional recipe-type experiments.

3. The 2nd year course will combine more advanced techniques with experiments that cross traditional boundaries. Experiments that focus on one area of chemistry will not be banned – it would be unproductive to ignore experiments such as the gas phase high resolution IR spectrum of small molecules just because such an experiment is clearly physical chemistry - but these will be included only where they can justify their inclusion in an integrated course.

4. The 3rd year course will consist of a mix of pre-planned experiments, and a range of projects.

5. Computing will be integrated into the course from the earliest stage, not just by providing students with ready access to computing facilities, but by encouraging them to regard computing as an essential part of practical chemistry.

The advantages

We would not be planning such a course without having been persuaded that the advantages that it can offer are worth the time and effort (and finance) required for development. These advantages include:

1. Providing students with a clear view of chemistry as a single coherent subject rather than as discrete areas.

2. Linking the practical experience of students more securely into the integrated lecture course.

3. Providing more opportunity for project work by encouraging students to widen their sights when devising experiments and giving them early experience working on open-ended experiments.

4. Using instrumentation more effectively by making all major items of equipment available to all parts of the course.

5. Extending the variety and depth of techniques experiments.

6. Fully integrating computer methods into the practical course.

7. Simplifying the addition of experiments in areas such as biochemistry which might fit only with difficulty in a traditional IOP course.

8. Developing experiments that may be of interest to students in related disciplines, such as physics or biochemistry, so facilities and expertise can be shared with other departments.

The Disadvantages

In setting out to develop this course we recognized that there might also be disadvantages in the new arrangements. Some problems doubtless will become apparent only when the course is fully operational; some, however, we can already foresee:

1. Experiments that cross the traditional IOP boundaries may not always fit neatly into a practical course, and those that involve links to areas such as physics or material sciences, though they may be of special interest, may require that students understand areas of science that have been covered only briefly in lectures.

2. Our plan is that the finished course will comprise a large pool of experiments. Even before this stage is reached, laboratory demonstrators will need a knowledge of a greater range of techniques, since they may be required to be familiar with methods well outside their field of research expertise. A greater degree of demonstrator training will therefore be required.

3. Our research suggests that the number of experiments currently available at other universities which might be included in an integrated course is surprisingly small. Hence a considerable amount of development work is required.

4. Devising new integrated experiments from scratch is in general more challenging than devising an experiment in a single area, since it may require input from, and collaboration among, several people.

Spreading the word

We hope that the developments underway at Oxford will be of widespread interest to those running chemistry programs elsewhere. We are enthusiastic about integration to form a single, coherent, unified course and believe that the course will, in time, form a valuable resource for the wider academic community. We intend to make available the outcomes of the work in a variety of ways.

We expect to develop, and publish, a number of new integrated experiments. All of the course material will be on the web, and we expect that most of this will be freely available outside Oxford. Some experiments may be located in other departments and run remotely; we expect in due course to develop links with other Universities to enable sharing of this type of experiment. We already have a substantial database of safety data for undergraduate use and will develop this further. When not required for the undergraduate course, the new facilities will be used to host summer students and to enthuse school students about chemistry, an initiative from which we hope all University chemistry departments will eventually benefit.

Perhaps most significantly, we hope to change student perceptions that the practical course is often the dullest part of a chemistry degree course. We would like students to come to regard the practical course as one of the highlights of their degree, mirroring the enthusiasm that they already feel for their final year projects. Much needs to be done, but we believe an integrated course offers a promising way to combine academic excellence with entertaining science.

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Acknowledgements

We are pleased to acknowledge support for ED, GR and NW in the form of a Teaching Excellence grant.