Group research projects: a framework for providing formative research experience for students

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Background and rationale

Biochemistry (BSc) students at Imperial take compulsory courses in core Biochemistry during the first two years, with accompanying laboratory practicals. These are run in large groups of ~60 (half the year group), with students following detailed step-by-step instructions to perform experiments, record their results, answer questions and hand in a write-up for assessment. While fulfilling many important functions, this format does not simulate the creative and investigative nature of the research process, and gives some students a misleading perception of the nature of bioscience research. At the end of the third year, when students undertake a six-week laboratory or literature Final Year Research Project in the lab of a member of academic staff, many are belatedly inspired to consider a bioscience research career, but are already set on other paths.

When designing a new Cellular Neuroscience (CNS) third year course option in 2003, I therefore incorporated a research project module to give students an earlier experience of genuine research. The two-week module requires students to conceive, design and execute their own unique research project in groups of three and write it up individually in the form of a scientific paper. The students receive interactive tutorials on experimental design, interpreting and describing data, and simple statistical analysis. The module has proved popular and has been running for five years. The CNS course accounts for 11.25% of the Biochemistry degree, and the practical module is worth 14% of the total marks for the CNS course. In addition, the final CNS exam (worth 80% of the CNS course marks) includes a data analysis question requiring students to apply analytical skills, concepts and knowledge acquired in this module. The module is entitled 'Effect of growth factors on survival, proliferation and morphology of cultured cells' and student numbers are capped at 35.

The learning outcomes of the research project module are that students will be able to:

- Recognise and implement key elements of experimental design;
- Work in a small group to set aims for, design and execute a unique research project within a set framework;
- Analyse their data with full consideration of statistical significance, magnitudes and trends;
- Present and describe their quantitative and qualitative data in the form of a research paper;
- Experience genuine research, problem-solving and team working; and
- Experience the creativity of research.

How to do it

This module comprises (1) two days of experimental design (4 x 2.5 hours), (2) laboratory work spanning two weeks to execute experiments designed, (3) five associated lectures giving background to assays, describing and analysing data and writing papers. Student outputs for the module are a plan giving details of their aims and experimental design (10%) and a write-up in the form of a research paper (90%).

The two-day experimental design phase preceding laboratory work is an essential feature of this module. Students work in groups of three to decide upon their own research questions and iteratively design their experiments. Complete freedom would be impractical, as teaching laboratory technicians need to ensure key equipment and materials are available, so it is important that a framework and parameters are provided to inform their planning. The research scenarios presented to students need to provide a good balance between giving a clear framework with broad aims within which the students should work, and allowing them freedom to design their own research.

The broad module aims are to determine the effects of two different growth factors on survival/proliferation of a cell line (and the signalling pathways underlying effects seen), and the effect of the growth factors on the morphology and relative number of neurons, astrocytes and oligodendrocytes cultured from dissociated cerebellum. Students are briefed on which assays, growth factors, signalling inhibitors and antibodies, plates, slides and cells are available, and are provided with a timetable for which stages are done when. For example, the cell line is only available on Monday and the cerebellum only on Friday, so clearly these are the days the cells must be plated; the day for immunostaining is timetabled as such; the signalling inhibitors and growth factors are only available on Tuesday and Friday. Within this timing framework groups are free to choose what they are interested in finding out.

Experimental Design Phase

This takes place in four sessions spread over two days. In **Session 1** students are given key background information, and provided with a briefing sheet laying out the broad aims of the research, a list of hardware, cells, antibodies, growth factors, signalling inhibitors etc available for their use, and the framework within which they will be working.

In **Session 2** students work (in threes) through stylised experimental design problems. These allow them to discover for themselves certain key elements of the experimental design that have been problematic in previous years, e.g. the necessity of replicate wells, essential controls, how to plate a certain number of cells per well, how to achieve a certain concentration of a growth factor plus two signalling inhibitors in the same well (dilutions), etc. After working on each problem, the groups report back and share their (different) solutions. The class discusses the merits of different approaches, and we come to a consensus on best practice.

During **Session 3** the groups of students design their own unique experiment. Each group decides what it wants to find out, e.g. the effect of a range of concentrations of the growth factors, the effects of a limited number of concentrations over 1, 2 and 3 days, the effect of different pharmacological inhibitors on growth factor effects, etc. One of the hardest lessons for them to learn is not to be overambitious. The temptation is strong to try to test everything, but this is not possible, as they will realise in Session 4. Decisions have to be made on priorities, the aims decided upon, and a course of action agreed by the three members of the group.

During **Session 4** the twelve groups report back their experimental design to the whole class. We discuss each plan, asking for clarification, making suggestions, affirming good ideas, etc, so that the class absorbs collectively ideas about potential pitfalls, good practice, etc. By the end of this session, each group of three will have a workable experimental plan to begin to implement after the weekend. In the remaining time, groups begin to work out their dilutions in readiness for the laboratory phase.

Laboratory Phase

In advance of the laboratory phase a practical schedule is given out, with step-by-step instructions for key techniques to be used, such as cell culture, immunocytochemistry, etc. The practical involves use of lamina flow hoods, and since we have only six of these in the laboratory, the class is divided into twelve groups of three, and most parts of the practical are run twice for half the class each time (6 groups). Students are required to work out their own dilutions and make up their own solutions. They must retain their pipette tips and solutions, etc., and keep them sterile for the entire laboratory phase, rather than having them provided each day by the teaching laboratory technicians.

Associated Lectures

Lectures on tissue culture and immunocytochemistry are given at the start of the module before the experimental design phase, and towards the end of the first laboratory week students attend a three-hour interactive lecture-tutorial on data analysis and presentation. Here tips are given on how to analyse their quantitative and qualitative data – such as not to do too much 'expecting' or worrying about what is 'right' and to simply report the findings as they are. Information on how to structure a paper, the necessity of a stand-alone Results commentary, how to write figure legends, etc, is also given and discussed.

Advice on using this approach

- Look for a research scenario that gives scope for students to design experiments to achieve their own aims, while taking account of teaching laboratory requirements and limitations.
- This approach could be scaled up to larger classes, but I would recommend that the experimental design sessions be run with a maximum of 12 groups; the plenary sessions where designs are shared and discussed would take too long with more groups. For larger classes this may mean running parallel sessions (if other facilitators are available), as a series of sessions with the same facilitator would take a great deal of time.
- Ideally, students would work in groups of two; pressure of numbers has meant that for this module they work in groups of three, which is satisfactory.
- This module runs in the third year, but the approach would be effective and of benefit to students in the first and second years, if time could be found in the timetable for a scaled-down version of the essential experimental design phase.

Troubleshooting

When I first designed the research project module, the experimental design phase did not include stylised experimental design problems for the students to work through (Session 2). Following the briefing groups began the iterative process of designing their experiments, reporting back at plenary and refining. Occasionally groups spent design time on flawed concepts which came to light in plenary, but required complete re-design of experiments. Although the lessons were learnt, it was frustrating for students to have to start again from scratch. Session 2 solves this problem by still allowing the students to arrive at their own solutions to problems, but within the context of a stylised framework. Once these truths have been absorbed, the design of the groups' own experiments will avoid these basic flaws.

A problem that I foresaw, but which has not actually arisen, is that of students designing ridiculously simple experiments out of laziness. To prevent this, the aims of the research given in the briefing information have been carefully considered to ensure that they cannot be met with an unacceptably small experiment.

A more common problem is that students design over-elaborate experiments doomed to failure by their complexity. The necessity of simplicity in design must be drummed into them. They find it very hard to accept!

Does it work?

Comments included in formal College course evaluation by students suggest that the objectives are being met:

- "The practical was very good because you actually had to think for yourself and plan your own experiments in groups, and it really helps with the final lab project at the end of the year"
- "The practical is very detailed and enables students to appreciate what goes on behind the planning of an experiment and interpretation of the results."
- "I really enjoyed your module and you made it interesting by involving everyone and making us think for ourselves with our coursework."

As part of a wider research project (see below), the 2007/2008 cohort was questioned about the CNS practical module; 93% of respondents agreed that it had been a valuable learning experience, 80% agreed that they had valued the experimental design component, and 87% agreed that the skills and concepts associated with designing, executing and writing up the practical were helpful preparation for the Final Year Project. Some of the students were also interviewed by a researcher, and the following extracts give insight into what students take away from this module:

- "[It] was the first time ever that we got a chance to design the practical ourselves and take it the way we wanted to take it, so up to that point in time we'd always been given protocols and you had to follow the protocol, they give you a recipe and you just do the recipe and that's it. But with that particular practical, that was the first time we were given freedom to design the practical on our own. Which was refreshing, but at the same time wasn't daunting because we got a lot of guidance and support throughout the way, so it was like somebody was holding our hand through the process as well, but it still felt good to actually design the practical."
- "I'm doing a literature project in my final year, so what I drew from that experiment was not actually the particular precise laboratory techniques but when I was coming to writing it up, we got a lot of tutorials on how to write up the data, analyse the data that we got and that really helped me to develop some sort of critical thinking and independent form of thinking and not really to accept a graph for what a graph is presented to show but read to see whether it's actually showing what it's meant to show. So that sort of critical and independent thinking came from that sort of practical."
- "[At] first we were really exciting but a little bit scared cos we didn't know, we hadn't planned any practical before, but in the end we felt really happy because we have achieved that in the end, it was really good."
- "It was a bit daunting at first but it was in such a way that it was very guided, as in guided throughout the entire process so even though it felt daunting at the beginning, eventually as the process went on you kind of get a better idea of what you, as in what the experiment is about and yeah because it's designing what you wish to test, your own parameters, so it's interesting because different groups would have different parameters as in experimental parameters and different groups would be testing different things so I though that was quite cool because we, all our lab reports won't be generic, depending on what you test that's how you analyse, and there's also different ways of analysing the data so it was very, I guess there's a lot more room for you to put in your own individuality into the lab report."

The strength of this module is that it gives the students the opportunity to be creative, experience conceiving, designing and executing their own research, and have ownership of their practical work, often for the first time. Because each group knows that their experimental conditions are unique, they are more inclined to have the confidence to report what they do find rather than worrying about what they should have found. All students gain from the experience. The keen ones relish the challenge to decide what to research and why. Those who generally do not bother to even read the practical schedule before they start have no choice but to engage with this session from the outset – they have to, or they will not have a practical to do, and will have nothing to write up. A number of the students who shine in this module, showing impressive originality and analytical ability, are doing poorly in the degree overall. All students gain experience designing, executing and writing a paper on genuine research. This not only helps them when they come to do their six-week research project in the final term, but the data analysis and report writing it entails is a transferable skill that will stand them in good stead in any sphere. Above all, the students begin to appreciate the creativity of research.

The downside to this module is the investment of time required for assessment. Students individually submit an experimental plan and a report on their research project in the form of a paper. Essentially, this is equivalent to reviewing 35 different research papers, and takes a considerable investment of time and concentration. It may be feasible to introduce a peer-review element to the assessment, and this will be trialled next year.

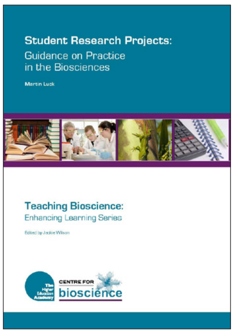
Further developments

Some students have great difficulty calculating dilutions for the practical, and since success depends on their having worked all these out before they come to the laboratory, I plan to include an additional troubleshooting tutorial (Session 5) at the end of the Experimental Design phase, during which students can complete their calculations and receive guidance where necessary.

I would like to timetable a writing-up workshop after the module, where issues arising from problems the students encounter when analysing their data could be raised, discussed (and resolved).

I am currently conducting a research project on the influence of different types of research-based teaching (including this module) on student learning and perceptions of bioscience research. The methodology involves a combination of Likert scale and open question questionnaires, and qualitative interviews with students at the beginning and end of their final year of Biochemistry at Imperial. The results will be disseminated towards the end of 2008.

Additional materials



This case study was written to accompany the Teaching Bioscience: Enhancing Learning guide entitled *Student Research Projects: Guidance on Practice in the Biosciences*, written by Martin Luck and published by the Centre for Bioscience. The associated website (www.bioscience.heacademy.ac.uk/resources/TeachingGuides/) contains a downloadable version of this case study and the following additional material:

- Briefing material for students.
- PowerPoint presentations for experimental design phase.
- Laboratory schedule.

Case Study published October 2008

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