

Multiplexing projects: supervising undergraduate research projects with larger cohorts

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Abstract

Almost all undergraduate students in the UK complete a final year research project or dissertation. In the molecular biosciences field, these projects are often based in individual research laboratory. However, with increasing student numbers, falling staff/student ratios and decreased funding for consumables, these projects are becoming unsustainable. At the University of Nottingham, we have developed a new model for cohort-based projects. These projects allow students to be taught key skills as a group, and then to apply their knowledge to individual projects. By streamlining communications, we are able to involve multiple members of staff and cover for staff absences. Feedback from these new-style projects has been extremely positive, and student engagement is high. Here, we share our experience of running multiplexed projects, and discuss the adaptations we have made to enhance the student and staff experience.

Main Text

For many students, the final year project is the most important part of their honours degree. In most British universities, undergraduate students spend a substantial period of time embedded inside an active research group, conducting their own research, culminating in a dissertation and often an oral presentation. The project is a student's first experience of real scientific research, and a successful outcome affects greatly the final degree grade. The project consequently it has huge importance for future employability. When these projects go well, it is an enjoyable experience, and can easily pull a student up a degree class. When projects do not go as expected, it can be a challenging experience for all concerned.

In recent years, financial pressures in the higher education sector have led to increasing class sizes, falling staff/student ratios, and decreasing funding for consumables available to supervisors. Student numbers have doubled in the past two decades, while the sector has been grappling with issues of equity, funding, and student support.

As such, this crucially important career stage for undergraduates is rapidly becoming no longer sustainable in its present form. Supervising and training three or more students in a large well-funded research lab, where several post-docs and PhD students are available to provide constant advice, is easily manageable. However, supervising higher numbers of students where there may only be the assistance of only one PhD student (or in some cases, no research staff) is neither feasible nor productive for either the group leader or to the graduate students involved.

In our department, we have ten research-active academics, who run various sizes of research group, subject to the uncertainty of the UK research funding landscape. Each year we supervise

between 30 and 80 project students studying microbiology or biotechnology. Roughly half are BSc undergraduate students on academic year-long research projects. The projects are conducted in parallel with taught modules, which adds an additional complication for the scheduling of lab-based activities to avoid clashes with lectures. In addition, we host taught MSc students on eight-week intensive laboratory projects over the summer period, as well as MSci students conducting year-long projects.

On one hand, we are in an enviable position where our student numbers have steadily increased due to the popularity of our courses. However, this increase has necessitated a re-engineering of student projects whilst maintaining alignment to the same curriculum goals and our external accreditation. We need to manage these larger cohorts whilst maximising learning outcomes over the project timeframe. Students also want a project with translational applications, which provides a wide range of transferrable skills for the continuously changing job market, which requires both practical and analytical skills, including basic knowledge of computer programming. An ideal student project would also produce preliminary data for the supervising academic, suitable for use in a grant proposal, or as the basis for another research project. Many students wish to extend their third-year research into their fourth-year projects, and these projects also act as recruitment tools for graduate research.

Over the past few years, we have developed a research project scheme, where students are enrolled in our '*Protein Production Framework*'. This scheme allows for parallel supervision of multiple students, each with their own research project, within a strictly controlled environment. It builds upon our expertise in molecular microbiology, structural biology and biophysics and involves academics working in unrelated disciplines whilst providing a route to utilising these techniques in their research.

***Protein Production Framework* group project**

We start by asking all academic staff if they have a protein of interest that they would like to have expressed in *E. coli*, with the eventual aim of pursuing a biophysical or structural characterisation. The protein can be from any organism, so long as either DNA or RNA (if the gene contains introns) is readily available. Students are then each allocated a gene target, and a supervisor who will provide biological context for the protein of interest. Allocation can take into account student preference (e.g. students with an interest in virology will be assigned a viral protein). The students meet with the supervisor to discuss the protein function, and the scientific questions, which need to be addressed (e.g. why the target was selected, why biophysical and structural data are required).

What is novel in our approach is the structured taught component, focusing on both key laboratory skills and theory. We have divided the project into 9 small modules, each focusing on a specific skill or technique. These include design of primers, transformation bacteria, etc. Each module consists of taught sessions to the entire cohort as well as relevant literature and a check list of skills attained. Some (eg primer design) include hands-on workshop time, while others include laboratory demonstration. This design means that many more academic staff can cover the necessary technical help required as each person could only need to be available for a couple of weeks rather than the entire year long project. This is also helpful for covering any unexpected or planned absences, such as illness or vacation.

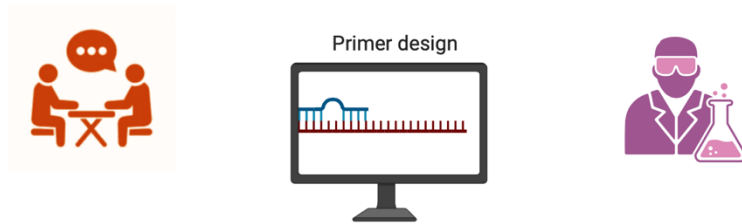
The practical training starts with a face-to-face session for the entire cohort on how to design primers. Students design their own primers to amplify their specific gene of interest (GOI), and

these are codon optimised and ordered from a commercial company. During the wait for primers to arrive, students undertake series of joint lab induction events and training sessions. These cover safety training, basic bioinformatics, as well as standard laboratory techniques such as how to use cloning equipment, DNA/SDS-PAGE gel electrophoresis, and how to make calculations for chemical solutions, how to make competent cells and how to perform protein quantification by various methods. The project workflow is shown in Table 1, and an overview is shown in Figure 1.

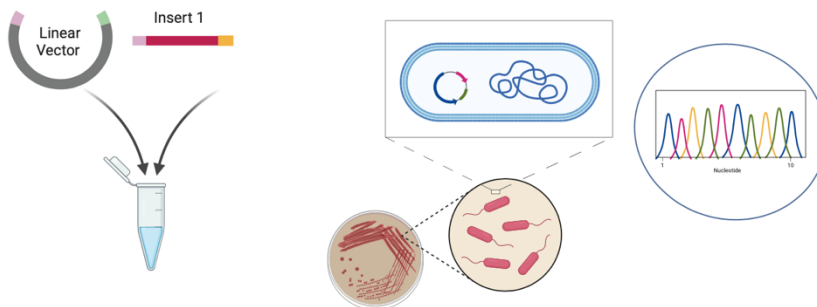
Step	Description
Face-to-Face Session	Entire cohort learns primer design.
Primer Design and Ordering	Students design and order primers.
Joint Lab Induction and Training	Training on bioinformatics, cloning, DNA/SDS-PAGE, chemical solutions, making competent cells, protein quantification.
Up-Front Training Benefits	Refreshing concepts, working independently, checklists for knowledge assessment.
PCR and Cloning	Amplifying GOI, cloning into bacterial vectors, transformation into <i>E. coli</i> , confirmatory PCR, plasmid extraction, Sanger sequencing.
Expression Trials	Expression trials in <i>E. coli</i> BL21 cells with varied temperatures and growth conditions.
Data Collection	Gather data for thesis discussion.
Protein Purification (Flipped Delivery)	Reading material, discussions, lab activities, consistent steps, teamwork.

Table 1 Structure of the programme.

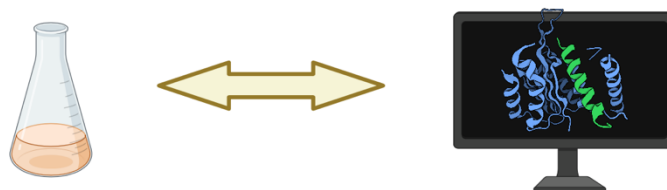
① Project planning, experimental design and Health and Safety inductions



② Molecular biology training and cloning into destination vector



③ Bioinformatic analysis and protein production



Protein analysis and characterisation

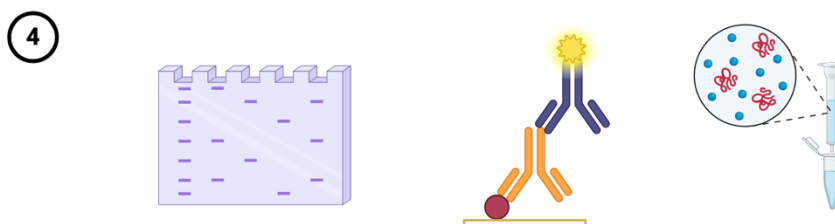


Figure 1. Overview of the *Protein Production Framework* group project

This up-front training allows students to refresh previous concepts, work independently and to prepare for the lab-based part of the project. Although students will have studied these during their curriculum, and may have performed experiments as part of practical sessions, they have not done this independently and we found that significant refreshing of background knowledge was required. Here, the mini-module format works well as the check lists allows knowledge acquisition to be assessed quickly and any deficits rectified swiftly. Where students are starting to fall behind, this model provides an excellent early warning system so that suitable intervention can be carried out in a timely manner.

Once this training is complete and the primers have arrived, we use PCR to amplify the GOI, and to clone it into a dedicated bacterial vector (pET18, Novagen). All the genes are cloned into the same expression vector using the same restriction enzymes wherever possible, and are transformed into *E. coli* Top10 for plasmid propagation. The students then perform standard confirmatory PCR and plasmid extraction, and samples are sent for commercial Sanger sequencing. When the correctness of the sequences is confirmed, the pET18-GOI clones are transformed into *E. coli* BL21 cells (made competent by the students) for expression trials. Again, there is no choice in strain of *E. coli*, and as such we have so far confined our targets to non-membrane associated proteins as the latter requires more specialist expression strains. Students are asked to express at a variety of temperatures, times, and to conduct growth curves to optimise the conditions to observe protein production upon cell growth. This provides a large body of data to ensure that if the student is ultimately unsuccessful in purifying their protein, will allow extensive opportunities for extended discussion in their thesis. Basic statistical analysis is also provided (i.e. BCA data analysis) as well as discussion on the importance of positive and negative controls.

Next, we guide the students through protein purification steps and theory in a flipped delivery manner, where student are provided reading material and protocols ahead of a discussion before moving to the lab-based activities. As much as possible, every step is consistent for every student, to allow efficient supervision, and also so that students can assist each other forming a team. This latter delivery mechanism is important as in order to teach each other they will need to have acquired a sufficient body of knowledge (which we have monitored through the checklist/mini-module format).

We also provide fundamental of bioinformatics using both web tools and protein visualisation tools such as Chimera and PyMOL. Through a series of in class workshop in which we show the students how to harvest the information on databases at the benefit of their project.

We observed that students who demonstrate greater participation are more likely to advance to the expected final stage of protein purification within the predicted time-frame. Conversely, those who exhibit lower levels of engagement or commitment tend to advance less in the project.

Supervision

Day-to-day laboratory supervision is mostly carried out by dedicated technical staff. In times of absence/summer holidays, we have also made use of technical staff seconded from the general teaching laboratories, as well as PhD students paid as demonstrators. Again here, the mini-module format allows efficient handover of the projects between staff so as to keep a continuity of supervision at all times maintaining research momentum.

Throughout the project, we hold weekly lab meetings for everyone at the end of each week (usually Friday afternoon), chaired by at least one member of academic staff and attended by the supervisory team. At each lab meeting, each student must present a single PowerPoint slide showing their results (e.g. gel photos, data plots, bioinformatic analysis) of their week's work for crucial discussion in an informal setting. This allows the chair to see at a glance how progress is being made and answer to any issues, providing an informal opportunity to share troubleshooting skills with the entire cohort. As on average around a dozen students are present, this can be very useful, as often the same issue is being experienced by multiple students. The weekly PowerPoint slides have also proven very useful to students when they

come to write up their projects, as it means that figures for the final report have already been created and labelled and can be easily transferred to the thesis. In addition, these presentations allow the supervisory team to more easily justify the 'supervisor allocated' marks in the final assessment. This score is designed to grade student engagement but it has the potential to be highly subjective. Finally, weekly presentations have allowed supervisors to measure engagement and understanding of concepts more directly, preventing anyone from falling behind.

Given the the informal setting, the lab meeting chair can encourage integration of students who may be less inclined to participate. This has had the result that students have become far more engaged throughout the project. We have found that they organically form a team with individual goals and overall inclusive support. Lab meetings also provide the basis for any early warning system to alert us to disengagement of students with their projects. Lack of engagement has previously been a significant difficulty with some students, possibly due to long-term effects of online teaching and expectation from the COVID-19 era. Through these group meetings, our student engagement with the projects has gone from variable to consistently good across the whole cohort.

Communication between staff and students

As there are very many staff and students involved, we make use of a Microsoft Teams site for all communications. In addition to a general public channel, each student has their own individual private channel, which also includes all academic staff. This ensures all communication about the project and all weekly PowerPoint slides are easily available and not scattered across multiple email accounts. As a result, any member of academic staff can answer questions for the benefit of the entire cohort, and has a good overview of progress. This is of particular use in the summer projects, when staff members alternate in taking annual leave, therefore the individual supervisor may not be around but the flow of information and the student learning experience are not interrupted and is easily accessible and trackable. This streamlined communication channel has had a significant positive impact on student engagement and attainment maintaining research momentum.

Adaptation

We have now run this scheme six times. Each iteration has resulted in changes, mostly around increasing the up-front group tuition over standard lab skills (e.g. making competent cells, bioinformatics), and the establishment of set protocols to benchmark the entire process. We have also included additional training, adapted according to availability of academic staff e.g. training in phylogenetics or structural prediction software - both of which will enhance the project, and gives the students the tools to consider their research results more deeply in the context for the biological question that they are trying to address.

Excellent student satisfaction

As student project engagement and project completion rates has risen so has the positive student feedback. In particular, students appreciate the weekly lab meetings: *"It was also good having everyone there because I felt like I could improve on my technique while also helping everyone in the group"* and *"weekly meetings really helped us stay on track"*. In the 2024 undergraduate cohort, about 40% have chosen to stay on for a fourth year MSci project. Longer term, the projects have opened up the opportunity for PhD study: the project *"...has*

sparked my interest in research ... looking at a masters or PhD will be something for the near future”, demonstrating that we are providing a thriving research culture.

Conclusion

Group leaders in higher education are encouraged to empower their teams, foster collaboration, and develop expertise through working collaboratively with colleagues to reduce workload and administer time effectively. Although initially very challenging, our experiences with larger cohort teaching has shown us the importance of innovating compared to the traditional approach of the students being allocated to the individual research groups. Whilst this scheme began as a method to deal with an immediate crisis (i.e. not enough supervisors, not enough resources, not enough supervising research staff), by adapting our teaching processes through collaborative working, we have developed a more innovative and systematic method of teaching project students.

Our solution involves protein production in *E. coli*, but the basic ideas (coordinated, up-front training, contact via Teams, use of technical staff, weekly lab meetings where everyone presents) could be used for a multitude of topics, including project involving tissue culture work, enzymology, spectroscopy etc. For example, we have discussed adapting the project to identification of antimicrobial resistance genes in a variety of environmental samples.

Our approach in developing a more structured project for a larger cohort, born out of necessity, has resulted in high student satisfaction, enhanced engagement, and more efficient utilization of academic staff time. There is a greater focus in the lab on techniques and production of results rather than on formal training or troubleshooting routine issues. We are sharing our experiences here as others may wish to adapt their projects as a result of similar challenges. We would be delighted to sharing materials and protocols upon request, for the overall benefit of the student learning experience.

Acknowledgements

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Further reading

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Authors

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Dr Ivan Campeotto obtained his BSc and MSc in Industrial Biotechnology from the University of Padua (Italy) and a Wellcome Trust funded PhD in protein crystallography from the University of Leeds (UK). His research work at King's College London, Imperial College London, and the University of Oxford involved determining the structures of enzymes and antigens for drug design and vaccine applications. His current research, as Assistant Professor at the University of Nottingham, focuses on structure-guided development of diagnostic and therapeutic solutions for Chagas and other neglected diseases. He co-invented a heat-stable malaria vaccine protein, currently in human trials in children in Africa.

Dr David Scott did his BSc and PhD at the University of Leeds (UK) before going on to post-doctoral work at the Universities of York, Oxford and Bristol (UK). In 2003 he was appointed as a member of academic staff at the University of Nottingham (UK) where he has been ever since. His research interests are in biophysical methods applied to structural biology, and he has worked on a wide range of biological systems that have necessitated the production of protein samples in different expression hosts. Since 2012 he has been Group Leader in Biophysical Methods as the Research Complex at Harwell (UK). He has taught biophysics, molecular microbiology and structural biology at BSc and MSc level for over 20 years to students from a diverse range of previous educational experiences.

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