Strategies for Enhancing Communication Between Students, Academics and Researchers Participating in Large-Scale Undergraduate Research Projects

Karen Mate[a], Carlos Riveros[b], Jude Weidenhofer[a], Belinda Goldie[a], Judith Scott[a], Pablo Moscato[b], Dan Johnstone[c], Elizabeth Milward[a]

Corresponding author: liz.milward@newcastle.edu.au
[a]School of Biomedical Sciences and Pharmacy, The University of Newcastle, Callaghan NSW 2308, Australia
[b]School of Electrical Engineering and Computer Science, The University of Newcastle, Callaghan NSW 2308, Australia
[c]The Bosch Institute and Discipline of Physiology, University of Sydney, Camperdown NSW 2006 Australia

Keywords: undergraduate research, communication, biomedical science

International Journal of Innovation in Science and Mathematics Education, *22*(5), 14-29, 2014.

Abstract

Spreading the word about science and inspiring people to connect with the processes and outcomes of science, whether as researchers, educators, students, industry professionals or consumers, is essential in forging stronger links among scientists and with the communities that stand to benefit from their work. How do we nurture inspirational scientific communication in the context of university undergraduate science education, particularly in large cohort settings that are often more mind-numbing than soul-stirring? Communicating your own discoveries effectively is the zenith of scientific endeavour. We have developed a large-scale original research experience for second or third year undergraduate biomedical science students. The students undertake 'mini' projects and present their research outcomes verbally, visually and in a written format suitable for journal publication. This helps students understand how science works and develops their ability to explain scientific concepts to their peers and others. To promote 'original research' to students in ways that inspire and motivate participation, we have also evolved strategies to help instructors and researchers communicate successfully with large student cohorts, including a wiki for secure data storage, FAQ sheets and databases of bioinformatics tools. Introduction of the research experience has improved survey scores overall and on items relating to communication. These strategies are applicable to any course seeking to introduce students to the practice of research and communication of research outcomes. Our experience suggests optimal multidimensional communication may be best achieved through instructors, researchers and students working together to develop effective stratagems for surviving and thriving in the information-dense, digital world.

Introduction

Communication supports engagement and trust between scientists and the community

While communication skills are essential for employability and social engagement in many disciplines, the ability to communicate effectively is of particular significance for scientists. Promoting science and motivating people to value and contribute to science, as researchers, educators, students, industry professionals, consumers or critics, is necessary to keep scientists in touch with each other and the world around them.

Rapid advances in biotechnology and other new scientific arenas tend to generate controversy and public concern. One of the most important predictors of public opposition to new technologies is a lack of trust in the professional advocates in these fields (Priest 2001). The building and maintenance of public trust in bioscience fields requires scientists who can engage in effective discussion and dialogue with the public about their research and its applications. Scientists need to appreciate the importance of communication and be able to engage both other scientists and the public using the most appropriate communication skills and strategies available, including new media such as blogs, wikis and podcasts.

The importance of communication skills has also been stressed in the United States science education policy document "Vision and Change in Undergraduate Biology Education – A Call To Action" from the U.S. National Science Foundation and American Association for the Advancement of Science (Brewer and Smith 2011): "Effective communication is a basic skill required for participating in inclusive and diverse scientific communities... Practicing the communication of science through a variety of formal and informal written, visual, and oral methods should be a standard part of undergraduate biology education."

Yet although it is universally acknowledged that science graduates should have a high standard of oral and written communication skills, industry employers and graduates themselves have reported that undergraduate science and biotechnology programs provide insufficient training in this area (Gray and Franco 2003; Australian Government University Experience Survey 2013).

Integrating communication training into undergraduate biology

There are several student and academic barriers to the integration of communication training into undergraduate bioscience courses (Edmondston and Dawson 2014; Edmondston et al, 2010a). Students often do not value training in communicating science to colleagues or non-scientists (Edmondston et al, 2010a). Lecturers were generally supportive of including science communication training in the curriculum but cited a numbers of barriers, notably an already crowded curriculum with other areas of higher priority and a perceived lack of interest among students (Edmondston and Dawson, 2014). Consequently most lecturers indicated that they would like science communication training embedded within existing units in preference to stand-alone units (Edmondston and Dawson, 2014).

An integrated approach, using a rich and relevant context, is well suited to the development of higher level process skills that include oral and written communication as well as critical thinking, quantitative reasoning, social responsibility and collaboration (US National Research Council 2000). Such an approach also overcomes the issue of "preaching to the converted" in specialised or postgraduate courses on science communication, which tend to be taken by students more likely to follow a career path in the science communication industry than research (Edmonston et al 2010b).

Enriching science communication through undergraduate research projects

One authentic way communication training can be introduced into the curriculum is to embed it within the context of research experience. Integration of *bona fide* research projects with undergraduate teaching brings faculty-based research into the classroom, with multiple benefits for all involved (Lopatto 2007; Krause et al. 2008; Wei and Wooden 2011). A research-inspired communication activity customised for a large enrolment first year physics service subject provided positive learning experiences for both students and academics (Kirkup and Bonfiglioli 2011). Even when communication training is not the primary goal, graduates involved in undergraduate research report significant gains in communication skills, in addition to improvements in independent achievement, learning and problem-solving ability (DebBurman 2002; Bauer and Bennett, 2003). Undergraduate research projects allow students to participate in many of the professional activities of the scientific community. Students acquire experience of written communication within the genres and conventions of the scientific literature, experience of oral presentation of challenging concepts and information in forms suited to the experience and expertise of the audience and experience of the use of new technologies to disseminate information to a wider audience. These alternative forms of communication require the development of substantially different sets of techniques and skills.

Effective oral communication of science encompasses the ability to access and evaluate the needs and priorities of the target audience and the development of empathetic skills to engage listeners, without compromising scientific integrity or accuracy (Bray et al., 2012). Introducing brief and simple oral communication tasks early in the undergraduate curriculum, with increasingly complex tasks at later stages, promotes the development of communication and presentation skills over time. Communication is a central aspect of transferable learning and this process should preferably take place in an authentic or real life setting, that represents tasks or activities which students will encounter as working scientists (Chan, 2011).

Scientific writing is also best learnt within the context of authentic scientific inquiry (Jerde and Taper, 2004; Moskovitz and Kellogg, 2011). Students benefit most from inquiry based writing placed within a realistic scientific scenario, using relevant forms of communication including the research proposal (Weigant et al, 2011; Stanford and Duwel, 2013), the review article (DebBurman 2002) and the experimental research report (Mate et al, 2013). An authentic writing task also requires a tangible and defined audience, so it can be structured and targeted appropriately. This can be achieved by encouraging students to see themselves as trainee scientists preparing their work for publication, with fellow students and staff as scientific readers and reviewers (Moskovitz and Kellogg, 2011). Incorporating these types of opportunities to practice and improve skills is a significant factor influencing the scientific writing performance of science undergraduates (Jerde and Taper, 2004).

The multidimensional nature of successful science communication

Traditional approaches to science communication education are often ‘one dimensional’, training students to disseminate science ‘to’ others but ignoring aspects of science communication such as dialogue and debate. Students benefit from developing good listening and response practices for effective dialogues with different audiences (Kirkup and Bonfiglioli 2011). They may also benefit from more critical awareness of different communication strategies, for example how communication can be used appropriately or inappropriately, to inform, persuade or mislead, or considerations of how effectively communication achieves its aims. Another dimension that is often overlooked relates to communications between academics, students and other stakeholders (whether other scientists or the community). Academics provide role models for students, both in the modes and manners of their communication with students and other stakeholder groups, and in displaying and encouraging disposition towards ongoing learning and improvement in communication.

Teaching science communication may be fruitfully construed as multidimensional, aiming to enrich the many facets of communication activities across different stakeholders, including instructors and researchers as well as students. Additional dimensions can be introduced by expanding the kinds of scientific information being communicated to include original research outcomes generated by the students themselves and by using a variety of tools and approaches to manage and exchange information effectively (Figure 1).

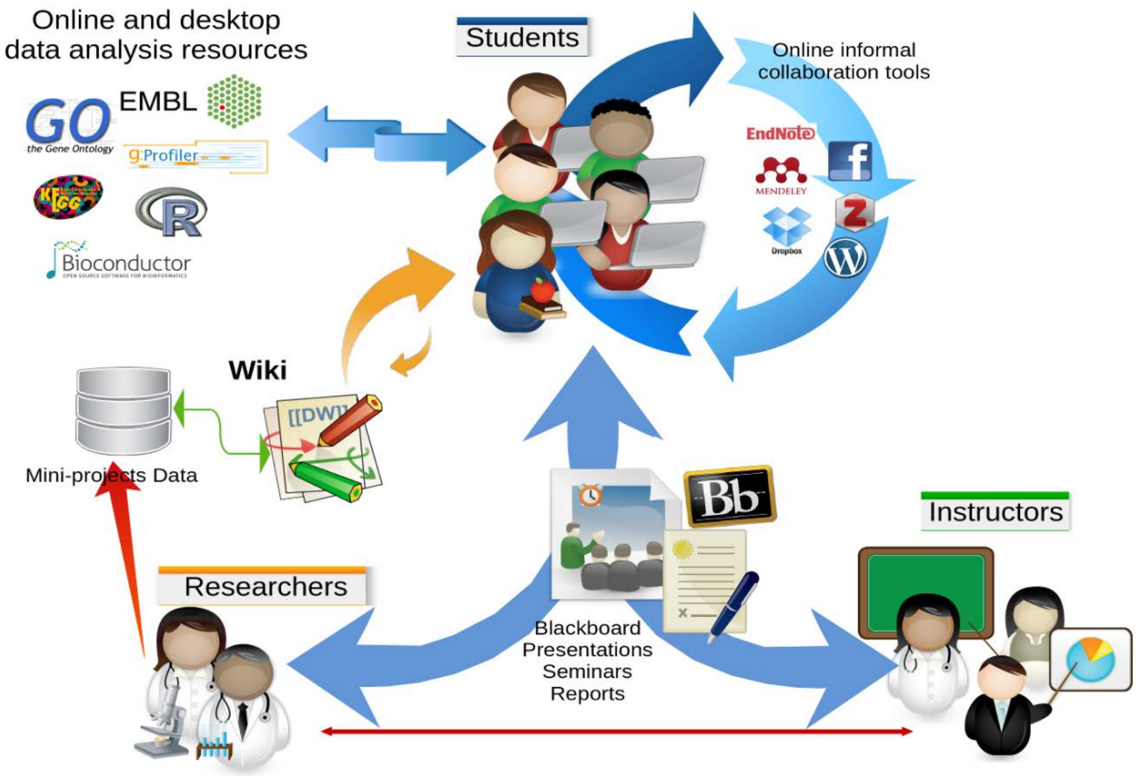

Figure 1. Enriching multidimensional communication in large-scale undergraduate research projects, across different stakeholders, including instructors, researchers and students.

As illustrated by Figure 1, enriching communication in this way entails not only using traditional media more creatively but also taking advantage of new media formats. Options such as short videos, podcasts, blogs and wikis are of increasing professional relevance, providing avenues for scientists to engage with the community through ongoing dialogue in written or oral formats. These technologies are increasingly used in tertiary science education to enhance writing, communication, collaboration and research skills (Placing et al, 2005; Kirkup and Bonfiglioli, 2011; Hamstra et al, 2011). For example, new media can provide “real world” publication opportunities for large groups of students and help them learn how to understand and cater for a variety of target audiences (Davis et al, 2009).

This descriptive case study discusses strategies for more effective ‘multidimensional’ communication between academics, students and external researchers, and for providing students with experience of real-world relevance in communicating research outcomes, in the context of a large-scale undergraduate research project experience.

Overview of the student research project

The course ‘Bioinformatics and Functional Genomics’ was introduced into the University of Newcastle Bachelor of Biomedical Science program in 2005 to provide students with skills and experience in the emerging disciplines of bioinformatics, ‘omics’ and related fields. It is currently taught over a single 13-week semester annually to about 65-75 third year undergraduate students, with the potential for scaling up to larger cohorts, as discussed further below. While students increasingly appreciate the importance of bioinformatics and the other topics covered in the course, evaluation surveys showed the large amounts of online data manipulation and number-crunching are a turn-off for some students in the absence of a real world context. To increase engagement and learning, a ‘mini research project’ was introduced in 2008. The assessment activities associated with the project presently comprise 40% of the total final grade for the course (Figure 2), although the format and assessment are subject to progressive alterations to optimise outcomes, as discussed in more detail below.

The mini research projects involve analysis and interpretation of original high-throughput datasets provided by local researchers, as depicted in Figure 1 above. This is usually, although not necessarily, microarray gene expression data from human patient groups, laboratory animal or cell line models and appropriate control samples. Students work with different datasets using various visualisation and analytical tools to find possible solutions for the research problem under investigation. The large amount of data generated in high throughput array studies and the many new online tools now available for manipulating and visualising data usually allow students to produce novel, biologically plausible findings that have not been published previously. This gives students the opportunity to experience the sense of discovery, personal contribution and intellectual engagement that can arise through participating in real-world research.

Shaping the research experience

In structuring the research experience, we find it most effective to have students undertake the initial phase of the project in small groups (usually three students per group) and complete the final part working alone, as summarised in Figure 2 below. Each group chooses a research question from a list provided (allocated on a first-come/first-served basis), is given access to the associated research dataset and conducts preliminary analyses to identify responses in molecular networks and component genes potentially relevant to the research question (‘discovery phase’). Once a list of interesting genes is obtained, each student then independently researches a different gene of interest within the context of the original research question, using bioinformatics tools to investigate properties of the gene and its products, including structure, functional domains, interactions and so forth. The students are required to generate a hypothesis based on their investigations (‘hypothesis-driven research’).

Commencing with a group work component provides students with peer support at the start, considerably reducing demands on staff and reducing the number of different research datasets required. This structure also encourages appropriate collaborative activities where students benefit not only from working effectively as a team in the initial phase but also from discussing and debating with each other different options and approaches throughout the project, including the final phase where each student works on their own gene.

Including an individual component gives each student the opportunity to demonstrate their learning and restricts ‘freeloading’. As each student is now working on novel unpublished outcomes relating to a distinct gene in the context of their own particular research question, direct copying from other students or the web and other unacceptable forms of collusion are generally not feasible options. This is reinforced by including questions relating to the practical activities in the formal exam at the end of the course, in addition to questions interrogating theoretical understanding. Assessment emphasises understanding of scientific approaches and, in group work components, effective teamwork, as opposed to simply generating results, and is considered in more detail below, in the context of effective communication between academics and students.

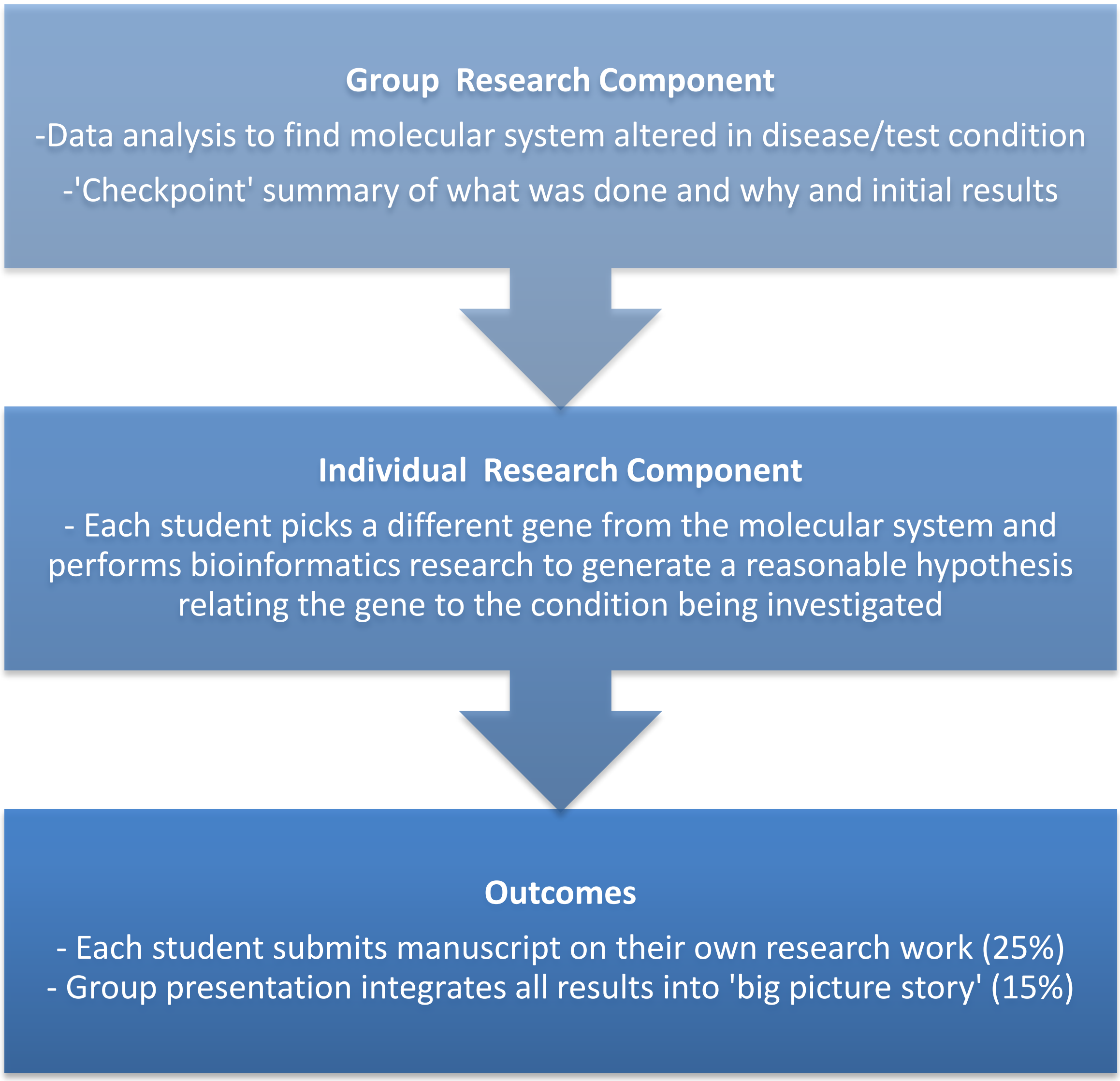

Figure 2. Overview of the mini-research project. Mandatory checkpoint on completing initial group phase ensures all students are on track entering the individual phase. Assessment weightings are given relative to the final grade for the full course.

Facilitating communication among students, academics and researchers using wikis

In establishing the infrastructure for this large-scale student research experience, we flagged three main requirements. First, participating researchers must be confident the original data they provide is securely stored, with appropriate access restrictions. Second, the management system must be student-friendly, with easy access to project information and datasets. Third, the system must be staff-friendly, requiring minimal time and effort to administer.

As illustrated in Figure 1, we use an Open Source ‘wiki’ - a web server platform for online creation and editing of content - that provides secure data storage, user-friendly interfaces and easy management of user access permissions and site content. The use of dynamic wiki platforms where students can contribute, modify and collaborate, paired with the feeling of performing real research, can serve as a motivator to improve student engagement and learning.

Academic support systems such as BlackBoard often provide wiki options but ‘in-house’ systems are not always easily accessible to researchers or stakeholders outside the institution, impeding external engagement. Wikis are available in many flavours, with different capabilities (see Wikipedia: comparison of wiki software). We chose DokuWiki (https://www.dokuwiki.org) for simplicity and ease of use. MediaWiki, the platform used by Wikipedia, may be more familiar to readers but is relatively complex to maintain and administer. Basic requirements of a suitable wiki are a simple structure and user management system, with some or all student and academic users able to edit and upload generic files and create content, and flexible access permissions for different users.

The wiki is accessed through the homepage of the University’s Priority Research Centre for Bioinformatics and Information-Based Medicine, allowing interested students to learn more about research being done locally. Users entering the wiki are provided with an overview of the mini-research project and how to get started, including selecting a project topic, accessing the relevant research dataset and the steps required to complete the group and individual components. The site includes a registry of participating researchers and the projects being offered and can be set up to include student ‘expressions of interest’ in projects, registration procedures linking students and researchers directly (without requiring course instructors to act as intermediaries), and automation of tasks such as deadline reminders and notification emails (e.g. annual reminders to researchers to update registry entries). The introductory section and the list of project topics can be provided to all site visitors without the need to log in or, if more security is desired, can be made available to all users with base level access through a single guest account.

Once a student group has selected a project, the group receives a generic username and password to access the restricted area holding the dataset for the project and any necessary explanatory information or other documents. The username is associated with the email of the group’s nominated contact person. Approximately 25-35 different datasets are used, each in its own restricted area. New sets can be added as required and once uploaded, are available indefinitely and do not need to be reloaded each year. Giving students editing and upload permission rights for their restricted section of the wiki lets them generate annotated meta-datasets, which can increase their engagement and sense of ownership of the data.

Course organisation and strategies for supporting effective academic communication

The course is centred around hands-on computer laboratory sessions with supporting lectures and discussions. Lectures on introductory theoretical aspects of bioinformatics and ‘omics’ include in-depth discussions with students about the research project and other practical aspects of the course. Topics include noise-reduction, normalisation and considerations in statistical comparisons of high-throughput data, and different strategies for minimising errors in hypothesis-driven or discovery-driven research. In our experience, students are more motivated to pay attention and usually come to understand concepts more easily when they must apply the concepts to decide which analysis strategy is most appropriate for their particular experimental question and the dataset used in their project. The project also gives students an opportunity to develop a deeper understanding of different approaches to scientific research because the initial group phase consists of discovery-driven research, where students are simply required to look for patterns and relationships in the data without making prior assumptions, whereas the final individual phase requires students to formulate hypotheses based on their own observations and investigations.

A two hour computer lab each week provides students with instruction and hands-on experience in dataset manipulation and bioinformatics analyses using a generic dataset. Students must then perform similar operations on their individual research datasets. Freely available online tools from the public domain are used for ontology analysis and identification of molecular networks, and for visualisation activities such as:
i) mapping molecular systems and networks using tools such as String (http://string-db.org/), ii) modelling protein structures with simple visualisation tools such as the NCBI Cn3D macromolecular structure viewer (http://www.ncbi.nlm.nih.gov/Structure/CN3D/cn3d.shtml) and iii) visualising evolutionary relationships through cladogram construction with ClustalW (http://www.ebi.ac.uk/Tools/msa/clustalw2/).

We focus on entry-level bioinformatics tools with simple interfaces requiring little specialist knowledge but we also encourage students to use and critique at least one other bioinformatics tool beyond those covered in the course, and some students employ relatively sophisticated approaches to answer specific questions arising in their project. Providing students with adequate guidance during the laboratory sessions is an essential ingredient for success. For long-term sustainability, particularly with large class sizes, lab instructions and associated lectures, and other resources need to be optimised as much as possible to minimise the load on academics without compromising learning. This requires effective communication by academics on several levels, including clear and comprehensive laboratory materials and support resources posted online in addition to on-the-spot guidance from laboratory instructors. (The term ‘instructors’ is used throughout this article to denote academic staff providing direct instruction to students in the course, as distinct from researchers providing original data who do not teach directly into the course. Both are part of the broader group termed ‘educators’.)

Helping students communicate science more effectively

As well as providing experience using simple bioinformatics tools, the project helps students gain deeper understanding of how science works and build experience in communicating scientific concepts and ideas to peers and others. As summarised in Figures 1 and 2 above, research outcomes are presented verbally, visually and in writing both in brief talks, detailed further below, and in a manuscript format suitable for journal publication. Each student must write their own small manuscript at the end of the project, describing both the group section of the project and their own individual research findings. The manuscript is in the format of the journal Medical Hypotheses, which includes an abstract, introduction, statement of hypothesis, evidence-based evaluation of the hypothesis and discussion. Specifically students are required to: demonstrate understanding of the research question and the technology and experimental studies underpinning the project; provide a descriptive analysis of the data identifying molecular systems showing statistically significant differences between experimental test and control groups; formulate a testable hypothesis; suggest a predictive model for the problem using bioinformatics approaches; consider biological implications and suggest experimental strategies for validating predictions. For examples of manuscripts and formatting rules, students are referred to the Medical Hypotheses journal, to reinforce the real-world importance of hypothesis-formation.

Assessment activities have undergone several alterations over the seven years the projects have been running. In general, as summarised in Figure 2, each group presents their findings both as a mandatory checkpoint hurdle at the end of the initial group phase (this can take the form of either a brief report or talk), and in an assessed talk at the end of the project.

Conveying their findings to their peers and academic staff helps students develop research communication skills within the supportive framework of the classroom environment.

In the final group oral presentations at the end of the project, the students form the pieces of their puzzle together into a story about what they did and why. They are required to explain the relevant background and the question being investigated by the group, then present a summary of the initial group analyses, each of the individual student investigations and the hypotheses developed. Specifically, the presentation should demonstrate understanding of the research problem and its significance, the analytical approaches used and their limitations, the hypothesis generated and proposals for how these could be experimentally tested in future studies. The emphasis is on the validity of the approaches used rather than what results were obtained. In addition to formal assessment, in some years small prizes such as gift certificates for the book co-op or the campus candy store have been given as 'audience awards' for the best presentations as judged by instructors, researchers and by the students themselves (a form of informal 'peer review').

To allow all students within medium to large cohorts to present, the amount of time for each student is restricted to a 'micro-talk' of around 2-3 minutes, based on the 'less is more' concept exemplified by the 'elevator speech' – a way of effectively pitching a proposal first popularised by Philip Crosby as "…an all-encompassing, action-producing set of ideas that you pronounce while on the elevator with the big boss for just 1 minute" (Crosby 1981) – and the '3 Minute Thesis' (3MT®), an academic competition developed by The University of Queensland, Australia, that challenges Research Higher Degree candidates to present a compelling oration on their thesis and its significance in just three minutes, in language appropriate to a non-specialist audience, using a single illustrative slide.

The micro-talk format requires students to focus on making a small number of key points strongly. It has essentially eliminated students seeking to be excused from group presentations because of anxiety issues since almost all students feel able to handle presenting for just a minute or two. This also facilitates the scaffolding of presentation experiences over the full degree program, allowing students to progress with less anxiety from 'micro-talks' to presentations of around 5-10 minutes in the capstone 3rd year laboratory research course and from there to longer Honours and research higher degree presentations.

Students are free to use any media and format they wish for the presentations however as the course aims at verisimilitude in terms of practices used by real-world scientists, the priority within the limited time available is on building familiarity with widely used tools rather than exploring novel presentation media, and generally groups elect to use conventional Powerpoint slideshows.

Helping academics communicate more effectively with students

Traditional perspectives on improving academic communication with students often focus almost exclusively on delivery of course content. While delivery skills and modalities are of course important, here we consider some other less obvious aspects of effective communication with large student cohorts, notably assessment and feedback. Poorly designed or badly communicated assessment or inadequate feedback are likely to lead to big upsurges in student requests for more information, guidance and help and to increased work burdens and stress for academics. We believe that, used effectively, assessment and feedback can be valuable tools in improving a range of different aspects of student-academic communication.

Before the project was introduced, the course was assessed by a formal theoretical final exam and a formal computer practical final exam, as well as two continuous assessment tasks - a computer laboratory report portfolio and a ‘simulated research’ report for which students were allocated a gene to study with bioinformatics tools. The intention behind the computer lab portfolio, report and formal practical exam was to help ensure students obtained practical, hands-on experience. Instead, poor attendance and disengagement during computer labs led to poor quality, last-minute portfolio and report submissions. The successful implementation of the mini-research projects has made all these assessments redundant, while at the same time greatly reducing student and staff workload and stress.

Assessment activities are reviewed and adjusted on an ongoing basis with a view to improving outcomes within the operational constraints of staffing and timetabling but in recent course iterations, as described earlier, assessment has typically consisted of either a group presentation or a brief written report as a mandatory checkpoint at the end of the group component, an individual manuscript, a final group presentation and a final theory exam. Importantly, the checkpoint activity at the end of the group phase is designed as a safety net to identify and assist struggling students at an early stage (Figure 2). Depending on staff-student ratios and other factors, this assessment can be conducted on a group or individual basis and can take any of a number of forms, such as a simple email, a brief report or an oral presentation. As the primary aim is to provide a check-point to keep the full class on track and ensure that all students transit smoothly from the group to the individual phase, this can comprise a mandatory hurdle without a formal mark or can be given a token weighting, for example 5% of the final grade for the course.

Marking criteria and rubrics are exemplified in Figure 3 for the main continuous assessment items (the final oral presentation and the manuscript). Criteria are provided early in the course, when the assessment is first announced. This is reinforced by supplementary information in lectures and online closer to the deadline on specific requirements, including general information on good presentation practices and scientific writing skills. Again clear communication to students in advance, not only of expectations but of tips for meeting these expectations, is a powerful aid in minimising student and staff workload burdens and can be as simple as permanently posting a set of clear guidelines and examples of good and bad practices on the course website.

Oral assessment marks are currently given on a group basis, with emphasis on how well the group works together to communicate their research story. Feedback can be provided effectively to large classes by a single online posting that summarises how good presentations addressed the criteria and how weak presentations fell down, along with ways to improve. This can be personalised by a brief email using a modular ‘cut-and-paste’ format to combine relevant comments for each student noting the broad area of greatest weakness to target for future improvement (e.g. content or presentation style or question responses) and referencing back to the class feedback for suggestions on how to improve.

As there is often little variation between cohorts with regard to communication skills, it is usually possible to set up a template and bank of personal feedback comments that address key assessment criteria and use these with few, if any, variations each year. As will be discussed in the next section, we have also taken similar approaches to other aspects of the course, including setting up a bank of online resources that can be used from one year to the next to facilitate communication and support student learning.

	Fail	Pass	Credit	Distinction	High Distinction
Information and Analysis	Most information and analysis incorrect Inadequate referencing	Adequate but major weaknesses e.g. serious errors, lacks relevance or depth, poor referencing	Mostly correct, but with minor weakness in information content, analysis or referencing	Good quality, relevant information and analysis Information sources appropriately referenced	Distinction *plus* inclusion of at least one relevant bioinformatics analysis not covered in the lab classes
Understanding	Inadequate explanations Question responses unsatisfactory	Limited or unclear explanations Question responses have major weaknesses	Clear, valid explanations Question responses generally sound and well-handled	Explanations and question responses show balanced consideration of relevant evidence	Distinction *plus* 'big-picture' understanding including significance & appropriate future studies
Presentation	Read off notes Hard to follow, not clearly audible, no visual aids e.g. diagrams, graphs, tables, flow charts	Doesn't engage audience well, unclear Poorly paced Ineffective use of visual aids	Engaging, easy to follow, clear, and audible. Appropriate use of visual aids	Engaging and well paced Visual aids well formatted, communicate complex concepts effectively	Distinction *plus* professional delivery - polished, engaging, carefully timed, outstanding visual aids.

Figure 3. Assessment rubric for oral presentations of the mini-research project.

Other simple strategies and tools for supporting and improving communication among students and the academic instructors and researchers participating in the course.

'New Biology' Fields emerging out of the Human Genome Project, such as bioinformatics, systems biology and personalised medicine, are interdisciplinary fields that encompass elements of computer science, mathematics and engineering, as well as biology, health and medicine, and entail a lot of computational analysis. There are recognised difficulties teaching computationally-intense bioinformatics and related areas to biology or healthcare students. It is unclear how successfully current teaching practices in these emerging fields engage and up-skill students from diverse disciplines. The best approaches for these students may differ considerably from what works best for students from computational science and related fields (Counsell, 2003; Johnson & Friedman, 2007; Van Mulligen et al, 2008).

As a result, these areas can already be stressful for biology and healthcare students. Unless well-managed, the addition of a research project has the potential to create further workload burden and stress for students and consequently for staff. Together with the potentially daunting prospect of having to come up with a novel finding that has not already been reported, having to make individual choices and decisions about what to do next in the research project where there is no right answer or clear next step, is usually the aspect of the course which students find most challenging. It is important to manage communication effectively to provide as much information and guidance as possible in lectures, labs and online postings to ensure all students are equitably supported and remain engaged without over-burdening instructors. For greater consistency, it can be helpful to make one staff member the designated ‘go-to’ person for questions relating to the projects. The aim is to help students overcome difficulties encountered in the training exercises with the generic dataset but not to help students with analysis of their own dataset, aside from general advice on how to approach the different kinds of problems typically encountered. For example, if students are having difficulties deciding what to do at a particular point, staff may discuss different options and factors which may be relevant in making the decision but will not tell them how to proceed.

In our experience, even just one or two very simple strategies and tools to help students resolve problems on their own without having to consult staff can make a large difference, not only to staff loads but also to student confidence in their ability to carry out an ‘original research’ activity. Students can be given online support resources such as FAQ sheets of answers to ‘frequently asked questions’ and flow charts suggesting different options for research directions, for example investigating structure-function relationships or regulation of gene or protein expression or protein-protein interactions.

Facilitating communication with researchers

One of the biggest barriers we have found in creating a successful nexus between teaching and research is the difficulty surrounding communications of the course instructors and students with researchers contributing data but not directly involved in teaching into the course. The researchers are usually time-challenged and, however well-intentioned and keen to attract students to their labs, receive few immediate rewards for engaging in the course. There can be large differences in the amount and quality of time different researchers spend interacting with students or course instructors and this can even vary widely for one researcher in different years, depending on competing commitments. Ensuring equitable one-on-one communication with students about individual research projects is therefore often a considerable problem for large cohorts, even if the course instructors base projects on their own research data and don’t need to mediate interactions with third party researchers.

Consequently, although we initially envisaged that researchers would work closely with students, to maintain equity and protect researchers we now restrict researcher involvement to providing the original data and to encouraging the students by showing interest in the findings, rather than assisting students with the data analyses *per se*. The main goal is to open communication channels between researchers and students genuinely interested in the research area, without making participation onerous for researchers.

Communication between students and researchers is also supported by activities such as ‘*Meet the Researchers’* sessions and ‘mini-conferences’ where researchers describe how they have used bioinformatics and related technologies in their research. These activities also provide students with role models in communicating the concepts, methods and outcomes of research in ways appropriate for the audience, as well as helping students to become more comfortable asking questions in a scientific forum. To further reduce workload implications, and because researchers contributing datasets come from a wide range of disciplines and often lack background in the specific bioinformatics skills taught in the course, researchers are not required to contribute to marking or other formal assessment. Instead, to provide more opportunities for positive interactions, researchers are encouraged to attend student presentation sessions and participate informally in judging awards for ‘best presentation’, as described previously.

Evaluation
The research project initiative has been assessed by annual online questionnaires, qualitative pen-and-paper surveys and student focus groups. Approximately 400 undergraduate students in six cohorts have undertaken mini-research projects. Introducing the research experience has significantly improved overall satisfaction with the course in university evaluations and average student survey scores on specific items interrogating outcomes related to different aspects of staff communication effectiveness (Figure 4). In addition, on average, at least 85% of students agree or strongly agree the project improves their bioinformatics understanding and skills, and instructors have noted overall improvements in formal examinations of practical skills. Consequently, as noted above, we now no longer need to deliver the formal practical computer exam. This has helped reduce workload and stress for course instructors, since designing and policing online assessment to minimise opportunities for academic misconduct can be onerous. Another benefit of the research project initiative is that, based on informal feedback from researchers, more students are now going on to Honours and PhDs involving bioinformatics and related areas and comments from students suggest increased interest in careers in this area (see below).

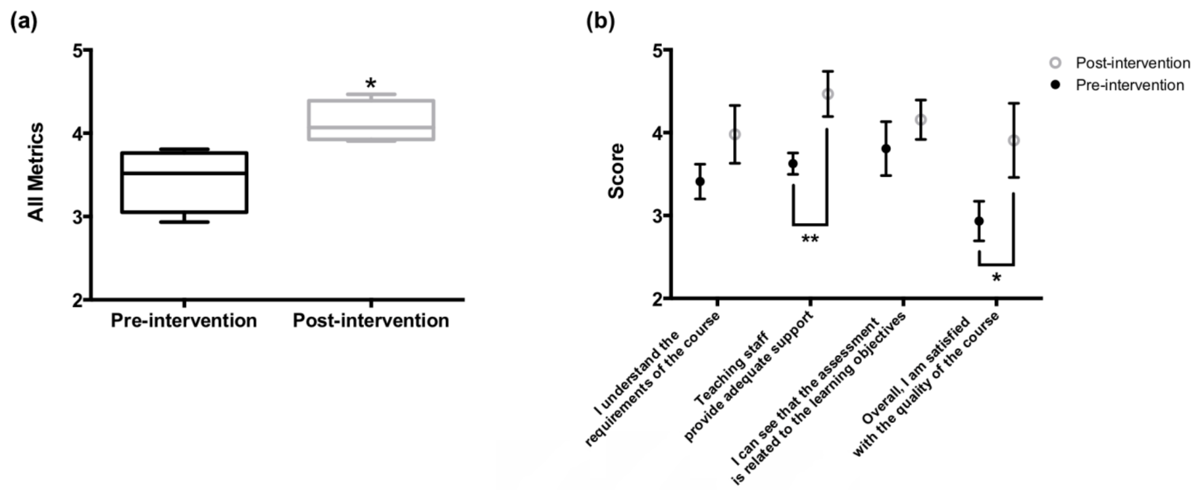

Figure 4. Improvements in student evaluations of communication-related outcomes. Student course evaluation data were averaged over four years before and four years after replacement of theory-based assessment items with the practical research project (‘intervention’). (a) The intervention significantly improved the average and range of student responses to all metrics assessed by the university’s course evaluation tool. (b) Individual metrics relating specifically to communication showed improvement in all areas that was significant or approaching significance (* *p* <0.03; ** *p* <0.01).

Student comments provide additional evidence of the success of the course in general and the project component in particular, in regard to communicating the importance of these emerging areas, engaging student interest (both in the practical aspects of the course as well as at the broader discipline level) and helping students improve their own communication skills through oral presentations.

“This year I understood the importance of bioinformatics and functional genomics and would be very interested in a future career in this.”

“I can now understand the potential possibilities of the bioinformatics discipline and that it will be a huge part of future medicine and research, hence i think it needs to be incorporated into other courses somewhat so students are more familiar with the content.”

"*Major projects were brilliant. Even though they were a little difficult to understand to begin with as we've never done anything like it before I greatly enjoyed putting what we were learning in the labs into practice and getting the opportunity to practice presenting to our class. I definitely feel that the project has helped me to understand genomics and proteomics a lot better and how bioinformatics is an important tool. Feedback on the projects and presentation was great as well*."

Scaling Up and Future Improvement

Using the wiki platform makes it possible to increase the number of projects considerably with relatively little additional administrative burden. The extent to which it is feasible to scale up the research exercise depends primarily on the number of available datasets and their size and richness. Some datasets are sufficiently rich to support two or more different groups studying separate research questions so around 20-25 such sets could support 100 or more students. The aim is for every student to be able to generate novel findings of their own with no overlap within the cohort. Other factors limiting the capacity for scaling up to larger cohorts include staff numbers and availability of venues, computers and other resources.

Communication and other key aspects of the research process such as hypothesis generation are not readily amenable to automated assessment. Managing assessable oral presentations by large cohorts of up to 100 or more students requires pragmatic approaches to running and assessing student communication activities without compromising learning or imposing excessive staff or student workloads. The micro-talk strategy can work well when there are several talks on related research areas that can be grouped together into 'mini-symposia' to decrease the cognitive load on the audience (including markers) but is less effective as the number of project topics increases. Scale-up options that could be used in future for larger cohorts include online blogs, short videos and podcasts, face-to-face or virtual online oral or poster conferences and 'speed-dating' variants of different kinds.

Another area for possible improvement is the 'longitudinal transmission' and evolution of findings from one student generation to the cohorts that follow. For example, if very large, rich datasets are available, this could take the form of a 'discovery diary' which details what has been done on a particular dataset, what worked and what did not. Each dataset could have its own report collection area of the wiki, where successive findings and any related materials are kept for others to check and harvest ideas. Access could be enabled relatively late in the course, once students have already proposed a path for their research, if copycat analyses or more serious plagiarism are a concern. We have not implemented this approach so far because of doubts about whether it is sustainable with the datasets we currently have available and concerns that it might instead tend to make the discovery process less rewarding and more difficult and frustrating for each succeeding generation of students. Ensuring there is genuine novel contribution and not simple transcription of previous results is also likely to impose considerable added work burden for staff and it is unclear that there would be sufficient gains in student learning to justify this.

Another possibility we have begun exploring is having the students themselves contribute to building up more online resources for the course, for example by helping populate databases of online bioinformatics tools, along with recommendations, tips and advice. This can provide keen students with an avenue for demonstrating higher level performance. However populating, curating and organising a resource of this nature can impose excessive workload on both instructors and students and only a few students each year have so far been sufficiently engaged or have had the time to trial additional higher level bioinformatics tools in their project beyond those specified, despite being given the incentive of potentially achieving a higher grade by demonstrating higher level skills (Figure 3). One option may be to make this a requisite for satisfactory or pass level performance on the project.

Conclusion

The experience gained through this initiative provides valuable insights that should benefit future undertakings of this kind. Showing our students we are open to exploring new ways of working and communicating with them helps encourage them towards ongoing exploration and discovery in their own lives. The tools and strategies we are using are applicable to any science course seeking to introduce students to the concepts and practice of research and the communication of research outcomes. Our experience suggests that optimal multidimensional communication may be best achieved by academics and students working together to develop effective stratagems for surviving and thriving in the information-dense, digital world.

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