A Model of Investigative Project Work to Teach Discipline-Specific Research Skills to Students Studying Advanced Human Physiology

Louise A. Lexis and Brianna L. Julien

Corresponding author: L.Lexis@latrobe.edu.au
Department of Human Biosciences, La Trobe University, Bundoora VIC 3086 Australia

Keywords: undergraduate, scientific communication skills, authentic student-centred learning

International Journal of Innovation in Science and Mathematics Education, *22*(4), 15-32, 2014.

Abstract

Evidence indicates that investigative project work promotes the development of research proficiencies essential for science graduates such as team work and oral and written communication skills. Designed from a constructivist approach, we introduced investigative project work in human physiology into a final-year human biosciences capstone program. To encourage the utmost authenticity, students are required to take on the role of a scientist in its entirety across a semester-long independent research project. In self-selected teams of 5-7 students, research projects are designed and implemented, and culminate with a team poster presentation, individual oral presentation, and submission of a journal article. In this paper we describe the project model in detail, including resource requirements, and place the intricacies of the model in context with the prevailing literature. Student performance over three years of the project is presented, along with student feedback and staff observations. We also discuss the challenges faced when developing and implementing the program. Preliminary evidence indicates that the project promotes the development of scientific communication skills, and as such, helps lead the students into a culture of professional practice. We believe that the model described in this paper could be adapted by academics across a range of science disciplines.

Introduction

Leading biological and life-sciences experts put out a call to educators to action change in the way we deliver undergraduate biology education worldwide (American Association for the Advancement of Science 2011). Overall, the plea urges educators to engage students as active participants in the scientific process so they can be better prepared for the biology-related challenges of the 21st century (AAAS 2011). Effective communication within and outside of a given discipline is an essential skill for all scientists, and it is suggested that practicing the communication of science through a variety of formal and informal written, visual, and oral methods should be a standard part of undergraduate education (AAAS 2011).

Prior to 2011, the advanced human physiology curriculum delivered at our institution did not engage students as active participants in the scientific process. Instead, the curriculum was heavily focussed on student learning of content, with 70% of the subject grade derived from the final exam on lecture content, and 30% from teacher-directed, cookbook-style practical classes. In-line with the call to action change, we set out to overhaul the curriculum into a capstone program (Julien, Lexis, Schuijers, Samiric, and McDonald 2012). Our goal was to develop a model of investigative project work within the capstone program that was embedded in the prevailing literature, but also adapted to suit our specific human bioscience context. The goal of the investigative project work was to engage students as active participants in the scientific process and promote development of key proficiencies such as discipline-specific research skills, team work skills, and visual, oral, and written communication skills.

Educators in the fields of gerontology, comparative animal physiology, advanced cell biology, and biochemistry have introduced investigative project work designed to promote research skills into their final year curricula, and importantly, have observed positive outcomes for their students (Caspers and Roberts-Kirchhoff 2003; Rivers 2002; Robbins, Kinney and Kart 2008; Wiegant, Scager, and Boonstra 2011). These models were implemented with small student enrolments ranging between 12-25 students (Caspers and Roberts-Kirchhoff 2003; Rivers 2002; Robbins et al. 2008; Wiegant et al. 2011), and team sizes ranging from 2-3 members (Caspers and Roberts-Kirchhoff, 2003) to 4-6 members (Wiegant et al. 2011).

When comparing the models, there is considerable variability in what the students actually do throughout the semester. In Rivers' and Caspers and Roberts-Kirchhoff's models, students work through a number of mini-projects which culminate in a student-driven, 3-4 week (Rivers 2002) or 6 week (Caspers and Roberts-Kirchhoff 2003) project. In Rivers' (2002) model the early classes focus on introducing students to the scientific process, presentation of data, finding and using scientific literature, and cell culture. In the ensuing weeks, students design experiments to test hypotheses determined by the topic of the week (e.g., relationship between stress and respiratory rate). There is also a focus on teaching students a range of procedures, for example, Western transfers, audioradiography, and DNA extractions. In the follow-up 3-4 week project, students develop an open-ended project on the topic of Stress-related Heart Physiology. In the early phase of Caspers and Roberts-Kirchoff's model (2003), students carry out an experiment each week that focuses on a particular test and its procedures (e.g., solution making, spectroscopy); in the student-driven 6 week project they are given test and control tissues and are required to propose a parameter that might be different between the two tissue groups and plan an experiment to test their hypothesis. Weigant and colleagues (2011) found that it was unworkable to allow students to collect their own data due to time constraints, and instead had students write and defend a genuine research proposal. In these models of investigative project work, students present their work in authentic manners, in the form of: writing and defending a research proposal (Caspers and Roberts-Kirchhoff 2003; Wiegant et al. 2011); individual and team research papers (Caspers and Roberts-Kirchhoff 2003; Rivers 2002; Robbins et al. 2008); and team posters (Caspers and Roberts-Kirchhoff 2003; Rivers 2002; Robbins et al. 2008). Adding to the authenticity, Caspers and Roberts-Kirchhoff required their students to submit their individual reports in the format of The Journal of Biological Chemistry.

While any model of investigative project work is inherently more student-centred than traditional cookbook-laboratories, the models described are somewhat limited in the degree of autonomy given to students. In most cases, the topic of student investigation is selected by the instructor (Rivers 2002; Robbins et al. 2008; Wiegant et al. 2011), and the topic is one that the instructor is very familiar with (Rivers 2002; Robbins et al. 2008) or even a specialist in (Wiegant et al. 2011). Selected literature on the topic is provided to students at the beginning of the project (Rivers 2002; Wiegant et al. 2011), and class time is spent providing students with lectures on research skills such as experimental design and data analysis

(Rivers 2002; Robbins et al. 2008; Wiegant et al. 2011). Instructors are also able to provide frequent, detailed feedback and to have regular in-depth discussions partly by virtue of the small student numbers.

The investigative project models described use the constructivist approach to learning which is well-suited for teaching research skills and scientific communication skills, and is supported by many higher education teaching and learning experts (Biggs and Tang 2011; DiCarlo 2009). This theory specifies that learning takes place as the student actively participates, interprets, processes, and constructs new knowledge (Biggs and Tang 2011). Constructivism is a context for teaching that emphasises what students need to do to build knowledge, which then indicates the sorts of learning activities that teachers need to introduce in order to lead students to achieve the intended learning outcomes (Biggs and Tang 2011; DiCarlo 2009).

The investigative project model that we designed and implemented in the advanced human physiology capstone program builds on the project models previously described. Our model was created with an embedded scaffold to support much larger cohorts of around 100 students consisting of teams of 5-7 members. In contrast to the dynamics of the other models, our students are required to take on the role of a scientist in its entirety, and with utmost autonomy and authenticity, across an entire semester (12 weeks). Student teams develop a study hypothesis based on a topic of interest, then design and conduct an experiment to test the hypothesis. Students then present the findings as authentic scientific presentations in the form of a team poster, and an individual journal article and oral presentation. The rigorous scaffold that we created supports students through the entire investigative process, from gaining literature searching and experimental design skills, through to writing a journal article manuscript. This scaffold does not impinge on student perceptions of independence, but rather provides a supportive learning framework. In this paper we present the model that we developed and honed, as well as preliminary evidence on the efficacy of the model in aiding our students to develop discipline-specific research skills, team work skills, and visual, written and oral scientific communication skills. We also discuss the challenges faced when developing and implementing the program which we hope will assist colleagues in a range of scientific disciplines to introduce similar project work into their curricula.

Investigative project model

Context of the project

The independent research project was introduced as part of a new capstone program (Julien et al. 2012) consisting of two semester-long final (third) year subjects: Advanced Human Physiology 1 (semester 1) and 2 (semester 2). These subjects are each equivalent to 50% of a full-time semester load and are taken by Faculty of Health Sciences students majoring in physiology and anatomy, or as electives by Faculty of Science, Technology and Engineering students enrolled in a biomedical science or nutrition degree; Table 1 provides demographic data on our students. Advanced Human Physiology 1 is a pre-requisite subject for enrolment in Advanced Human Physiology 2 and all students complete two semesters of systems physiology at 2^{nd} year (midpoint) level. Student enrolments in the capstone program have ranged from 80-115. The independent research project is conducted over the entirety of Advanced Human Physiology 2 (12 weeks; 13 weeks prior to 2014) and is completed in a weekly 3-hour laboratory class, and a weekly 3-hour guided-independent learning block. The guided-independent learning block is listed in the official subject timetable, but has no face-to-face classes. The subject also has 4 x 1-hour lectures per week, and these are independent of the research project. Ethical approval was obtained from the Faculty of Health Sciences Human Ethics committee to conduct the student project (reference FHEC12/105) and to publish student grades and student feedback arising from this work (reference FHEC 12/147 and 12/170).

Table 1: Student demographic data

	Frequency		
Variable	**2011**	**2012**	**2013**
Degree major			
Bachelor of Health Sciences	44	40	47
Bachelor of Biomedical Science	33	31	21
Bachelor of Human Nutrition	14	11	6
Bachelor of Science	2	8	2
Other	13	7	4
Gender			
Female	62	55	44
Male	44	42	36
Career aspirations			
Further study			
Allied health profession			
Physiotherapy	15	18	15
Audiology	1	1	1
Chiropractic		1	1
Exercise physiology / science	4		
Occupational therapy	3	1	2
Orthoptics	2		
Osteopathy	1		
Podiatry		1	2
Prosthetics & Orthotics	1		1
Speech pathology	7		
Honours			
Anatomy & Physiology		1	2
Biochemistry	1	1	
Science / Biomedical Science	3	1	
Psychology	1		
Medicine	13	4	6
Dietetics	13	4	2
Paramedicine	4		
Dentistry / oral health	3	2	1
Medical radiations	3		
Master of Science	1	1	
Master of Public Health	2		
Health Information Management	2		
Pharmacy	2		1
Optometry	1		
Nursing			1
Epidemiology			2
Biotechnology & Bioinformatics	1		
Teaching	1		1
Health promotions	1		
Psychological sciences			
Massage therapy	2	1	
Employment			
Scientist	6		
Nutritionist	1		
Accountancy	1		
Pharmaceutical representative	1		

Health services	1		
Responses	*98*	*37*	*38*
Total enrolment	**106**	**97**	**80**

Curriculum design

Learning outcomes

The independent research project was designed from a constructivist approach, and with an embedded scaffold, to promote authentic student-centred learning where students take on the role of a scientist in its entirety. The intended learning outcomes are for students to be able to: (1) Design and implement a research project that demonstrates application of physiological knowledge and skills; (2) Construct a journal article that illustrates, interprets and evaluates the outcomes of a research project in a written scientific format; (3) Design a team poster that visually illustrates the outcomes of a research project in scientific format; (4) Create an oral presentation that illustrates, interprets and evaluates the outcomes of a research project in an oral and visual scientific format; and (5) Employ well-developed team work skills to manage and organize implementation of a research project. To attain these learning outcomes at an excellent standard, students are required to demonstrate all six cognitive levels of thinking, as defined by Bloom (1956): knowledge, comprehension, application, analysis, synthesis and evaluation, as well as the highest level of cognitive thinking, creation.

Assessment tasks

The assessment tasks, designed to promote attainment of the intended learning outcomes, are: the presentation of a team poster, individual oral presentation, and individual journal article submission. The poster and oral presentations are presented in the same format as for an annual meeting of The Physiological Society and take place in settings designed to mimic a typical scientific conference. The journal article is written in the same format as a submission to The Journal of Physiology. The project was thus designed to promote the development of discipline-specific research and communication skills and therefore lead students into a culture of professional practice.

Scaffold

The complex scaffold embedded within the investigative project model provides a support system for large numbers of students that fosters authentic participation in the scientific process, but does not compromise student creativity and autonomy. At the beginning of the project, students are provided with a detailed hard-copy manual which contains intended learning outcomes, a suggested timeline for the project, information and tools to assist with project design and implementation (available equipment list, project proposal template, informed consent template, contact details for laboratory staff), team information (team agreement template and review of the team process template), and assessment guidelines and rubric marking schemes for the poster presentation, oral presentation, and journal article. An electronic copy of the manual is placed on the student Learning Management System (LMS) along with discrete access to each of the fillable templates, as well as award winning posters, sample journal articles, and poster and oral presentation *PowerPoint* (Microsoft, Redmond, WA) templates. Although students are expected to act independently throughout the project, each team is assigned an academic advisor whose role is to provide advice throughout the project when deemed necessary by the students. This support system was adopted as it has been reported that students can become anxious in situations when teaching styles are excessively student-centred and lack structure, guidance and support (Felder and Brent 1996). Each team is provided with their own team forum on the LMS to provide an electronic means of communication within teams. The advisor has access to the team forum and can communicate via this means as well as via email or face-to-face. To address diversity in student research skills and ensure students are prepared to undertake the independent research project, preparatory activities were introduced. Students complete (outside of class time) four online assignments (two in Advanced Human Physiology 1 and two in Advanced Human Physiology 2) designed to promote skill development in the areas of scientific literature searching, analysis of a research article, experimental design, and scientific presentation skills. Students have access to unlimited attempts of the assignments and there are no time restrictions. Also, in Advanced Human Physiology 1, students participate in team work in which individual accountability and team peer review processes occur. The chronology of the preparatory assessment tasks was strategically devised such that the students gain research skills that support them through the various stages of the independent research project.

The curriculum design illuminated in this manuscript has been reviewed externally by an expert in curriculum course design and assessment as part of the Australian Innovative Research Universities Academic Calibration Project (Innovative Research Universities 2014). The curriculum described in this manuscript received the highest possible scores for all components of curriculum design. Figure 1 provides an overview of the independent research project.

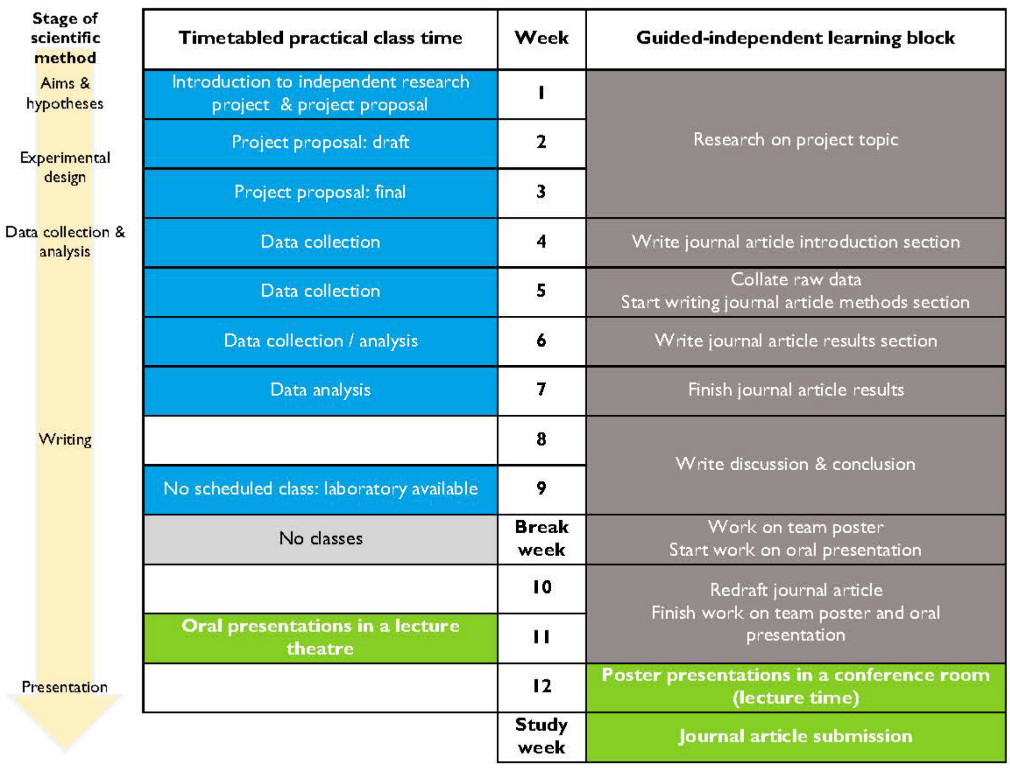

Figure 1: Overview of the independent research project. In non-labelled weeks, students undertake non-independent research project related activities. Students have 3-hours of timetabled practical class time per week and a weekly 3-hour guided-independent learning block. The 3-hour guided-independent learning block is listed in the official subject timetable but has no face-to-face classes. Prior to 2014, this project was conducted over 13-weeks.

Team selection and project topics

In the first practical class, self-selected teams of 5-7 members are established. The biological and life-sciences are collaborative scientific disciplines; therefore, team participation is an important aspect of a curriculum promoting authentic participation in the scientific process (AAAS 2011). The creation of teams with 5-7 students is based on research indicating that this number is ideal for effective team work (Smart and Csapo 2003) and is consistent with other project models (Wiegant et al. 2011). There were 18 teams in 2011, 17 in 2012, and 14 in 2013.

Teams are encouraged to assign a team leader and think about, discuss, and agree on issues relating to team goals, member roles, interpersonal relations, team processes, and accountability. Indeed, it has been shown that team cohesion, trust within the team and member awareness of their obligations, expectations of others, and working relationships are improved when teams establish ground rules at the beginning of a project (Whatley 2009). After a team agreement is completed, students are asked to choose a topic area for their projects. Topic areas are limited to available laboratory equipment for testing on humans and typically encompass the areas of exercise physiology, musculoskeletal physiology, and neuroscience.

Research proposal

After choosing a topic area, teams review the relevant literature, devise a hypothesis and aim, and design an experiment to test the hypothesis. Importance is not placed on the novelty of the project; in fact students are informed that they can replicate an existing study as long as they acknowledge that this is an aim of their project. The priority is that students devise a scientifically-sound project that is achievable within the available time. Most often advisor feedback suggests that students refine their project to make it less ambitious. A research proposal is completed early in semester by filling in a provided template which has the following sections: project overview (title, hypothesis, aim, experiment design, statistical analysis, and methods), ethical considerations, team member tasks, resources required, schedule for data collection, and information and consent forms. Advisors assist students with the completion of the proposal; this typically includes providing positive feedback on the proposal and making suggestions for fine-tuning the project prior to the commencement of data collection. Examples of student research project titles are shown in Table 2. Our observations suggest that students prefer to develop projects that have some inherent novelty rather than replicating a published study. Few projects are directly affiliated with authentic research of academic mentors; rather they are aligned with student areas of interest, with the available equipment, and students' familiarity with the theoretical and practical aspects of the topic.

Table 2: Examples of independent research project titles.

Effects of different music genres on brain activity, heart rate & mental arithmetic performance
Vision and gender: what impact do they actually have on single limb balance?
The effects of recommended doses of caffeinated Powerade on isolated skeletal muscle fatigue
The importance of visual aid in control of upper limb goal directed movement
Motor learning associated with toe typing skill
The effects of cognitive arousal on blood glucose concentration in a glucose tolerance test
Cognitive effects of pop and classical music on undergraduate university students
The effect of pre-workout supplementation on sensory awareness and bicep muscle fatigue during resistance training

The effects of breakfast on cognitive performance and haemodynamic factors in university students
Sex-differences in complex motor performance and learning in a mirror trace task

Data collection and data analysis

The intricacies of this component of the investigative project model were designed to promote the core competencies of communication and collaboration, features that should be included in all undergraduate biology curricula (AAAS 2011). Data collection occurs over a 2-3 week period. All students are required to act as a participant for their own team and another team; this ensures that teams have adequate data for statistical analysis. Advisors are present to assist students when required. If the timing of the class does not suit the constraints of the project, or teams need additional time for data collection, the team leader can contact technical staff to book the laboratory and equipment outside of class time. Upon completion of data collection, teams work with their advisors and/or a statistics expert to complete statistical analysis. Successful data collection and data analysis processes thus require students to communicate and collaborate effectively both within and outside of their team.

Scientific presentations

After data collection is completed, students work on their team poster, individual oral presentation, and individual journal article. Students are encouraged to seek feedback on their work from both peers and advisors; however, advisors do not take the lead due to the importance placed on student initiative. Peer review is encouraged as it is well established that participation in this process promotes the development of communication skills (Lundstrom and Baker 2009).

Poster presentation

Poster presentations are an important aspect of scientific meetings that deliver high quality science communication; however, they offer a different medium from oral presentations and published papers (Erren and Bourne 2007). A poster is a snapshot of a scientific investigation constructed primarily of visual displays of data with minimal supporting text to provide context, interpretation, and conclusions (Erren and Bourne 2007; Hess, Tosney and Liegel 2009). The goal of a poster presentation is to engage colleagues in a dialogue about the work, with the potential for more in-depth conversation and personal interaction than oral presentations (Erren and Bourne 2007; Hess et al. 2009). Posters have been recognised as a valuable tool for teaching and assessment because they can provide an authentic mechanism to promote team work, the development of presentation and communication skills, and enhance critical thinking and analysis skills (Bracher 1998; Costa 2001; Hess and Brooks 1998; Moneyham, Ura, Ellwood, and Bruno 1996).

Independent investigations are presented as an A1-sized colour team poster in the same format as for an annual meeting of The Physiological Society (2011); this contributes 10% of the subject grade (visual presentation 20%; language 20%; content 40%; and an ability to answer questions 20%). A poster template in a typical format for a Physiological Society conference is provided for students, as well as internet-links to award-winning posters. Towards the end of semester, teams are required to submit the completed posters as a *PowerPoint* file. Subject coordinators are responsible for organising the printing and display of the posters at the venue on the day of the presentation. Each team is assigned an examiner, and a moderator for the visual and written component (both are advisors for different teams). Examiners have access to the electronic version of the poster for at least one week prior to the presentation so they can assess the poster and formulate a question for each team member to be asked at the poster presentation.

In the final week of semester all teams, advisors, and invited guests come together in a conference room at our institution, an ideal authentic setting for the poster presentation. Upon arrival, staff and students are offered light refreshments, and students are handed voting forms for the best team poster to engage peers in a dialogue about the work. Students then locate their poster and wait for the examiner to join the team and begin the oral assessment. The examiner is responsible for asking each team member a question and assigning a mark to the poster based on the marking scheme. On completion of the oral assessment, students view other team posters and ask questions of the other teams. Students individually vote for the best team poster, and prizes (movie tickets) are given to the winners at the conclusion of the session.

Oral presentation

The ability of a scientist to clearly and logically present scientific results verbally is an important attribute for a successful scientific career (AAAS 2011; Bourne 2007). Oral presentations encourage broader dissemination of scientific work and illuminate work that may not receive attention in written form (Bourne 2007). Thus, it is important that science graduates attain proficiency with their oral communication skills, and as such, this was included as an important outcome of our investigative project model (AAAS 2011).

At the end of semester, each student delivers a 10-minute oral presentation in an authentic setting (lecture theatre) in the same format as for an annual meeting of The Physiological Society (2011); this contributes 10% of the subject grade (visual aids 20%; oral presentation 40%; and content 40%). The presentation is 8-minutes, with another 2-minutes allocated for questions from the audience. The presentation is given to approximately six student peers who are not part of the same team, and two examiners. Students are required to submit a *PowerPoint* file on the day of the presentation for the purpose of examiner access, and are also required to bring an electronic copy to their presentation. Each student is required to participate as a peer-reviewer for one presentation which includes asking at least one question of the presenter. The time allocation for the oral presentation is taken from the 3-hour practical class time-slot. There are 3 x 2 concurrent sessions held for each of the three practical class time slots.

Journal article

The concept that science graduates should be proficient scientific writers is well established. A key role of a scientist is to disseminate research findings, and this occurs to a large degree via the publication of journal articles (AAAS 2011; Bourne 2005). ‘Learning by doing’ is a generally accepted phenomenon, and it is suggested that students might also develop writing skills through cognitive apprenticeship training programs (Kellogg 2008). Although a cognitive apprenticeship is beyond the constraints of our program, we established a framework designed to engage students to ‘learn by doing’. We encourage students to model their own journal article on a published original investigation from The Journal of Physiology, and seek feedback on their work from fellow students and their advisor.

Each student writes up all stages of their independent project as a 1200-1500 word journal article in the same format as for The Journal of Physiology (The Physiological Society 2013) with minor modifications; this contributes 15% of the subject grade (presentation / formatting for Journal of Physiology 20%; language 10%; non-technical summary 7.5%; abstract 7.5%;

body of research paper: introduction, methods, results, discussion, conclusion 50%; and referencing 5%). Students are required to use *EndNote* (Thomson Reuters, Carlsbad, CA) referencing software; this bibliographic software is available to staff and students of our institution free of charge. To support this, we provide students with a brief 'how to' guide, consisting of screenshots and instructions for carrying out basic tasks in *EndNote*.

Marking and assessment protocols

Marking of posters, oral presentations, and journal articles is conducted by the academic staff in our department who have all acted as project advisors. All advisors are trained scientists who have experience in presenting at scientific conferences and preparing manuscripts for publication as well as supervision of honours (and frequently PhD) students. Examiners are provided with detailed rubric marking schemes to use for marking each assessment task. A moderation system was implemented in which posters and oral presentations are marked by two examiners, and a final grade is decided on. For the journal article, each advisor is responsible for marking the journal articles written by members of their team(s). The moderation system requires each pair of examiners to swap and mark 2-3 papers and for marks to be adjusted, if required, based on each person's completion of the marking rubric. The use of the detailed marking rubrics by experienced scientists has resulted in consistent grades requiring a minimal amount of adjustment to achieve consistency.

Staffing and resources

Technical staff and laboratory equipment

Two experienced technical staff members prepare experimental setups for the duration of data collection. Technical staff also order equipment that is not readily available (within reason) and nutritional or ergogenic supplements required by teams. These staff members are on-hand during data collection for troubleshooting and general advice.

Sufficient laboratory space is required to allow multiple teams to collect data simultaneously. We utilise two adjacent physiology laboratories (176 m^2 and 143 m^2 in size) with fixed and moveable benches which accommodate different types of experiments. The laboratories contain desktop computers which are connected to two-channel PowerLabs (ADInstruments, NSW, Australia) and each computer has *LabChart* (ADInstruments, NSW, Australia) software installed. An array of transducers is available which allows acquisition of a range of physiological data including electromyograms, electrocardiograms, electroencephalograms, finger blood pressure pulse, thoracic/abdominal circumference, gas concentration, temperature, grip force, airflow and volume, and blood pressure. Treadmills and cycle ergometers are available for exercise physiology-related projects. Other equipment such as sphygmomanometers, stethoscopes, Douglas bags, stopwatches, tuning forks, weights, and Von Frey hairs are also available. A full list of available equipment is provided to students in their project manual and protocols devised by ADInstruments are also made available on the LMS.

Academic staff and administrative support staff

Ten academic staff members acted as team advisors in 2011, 18 in 2012, and seven in 2013. In 2011 and 2013, each advisor took responsibility for two teams, and in 2012 each advisor took responsibility for one team only. A staff member with expertise in statistics is available to provide assistance to teams on how best to analyse their data. An administrative officer in our department arranges printing of project manuals and marking schemes, organises best team poster prizes and refreshments, and helps to setup the conference room for the poster session. Funds for printing, prizes, and refreshments are provided by our department.

Institution infrastructure and support services

In addition to appropriate laboratories, a conference room is used to provide an authentic venue for the poster presentations. Similarly, multiple lecture venues are used for the oral presentations. We suggest using authentic settings if possible, or at least holding the presentations in different rooms from regular classes as we believe it helps the students identify with the role of a scientist, and less so with that of a student undergoing assessment. The LMS is essential for posting materials relating to the project and setting up drop boxes for assignment submission. Information technology support for staff is also required when problems arise.

Student performance, student feedback and staff observations

The independent research project requires students to take on a complex and challenging task, thus, it is important to monitor student success, as well as the impact of the curriculum on student perceptions of the project and their learning. It is also important to gather information regarding staff observations, and together, these data inform ongoing refinement of the project.

Student performance

Statistics

Comparisons between groups for each of the three assessment task scores (2011-2013 combined) were made by one way analysis of variance. If significance was determined, a Tukey HSD post hoc test was used. Significance was established at the 95% confidence level ($p<0.05$).

Assessment scores

Student scores for each assessment task in 2011, 2012, and 2013 are presented in Table 3. The journal article scores were significantly lower ($p<0.05$) than the poster and oral presentation scores.

Table 3: Student grades for the independent research project assessment tasks.
^ Significant difference ($p<0.05$) between poster and journal article marks. * Significant difference ($p<0.05$) between oral presentation and journal article marks.

Team poster			
	2013	**2012**	**2011**
Mean	82.3	79.9	85.4
Standard deviation	7.5	7.9	7.4
Median	81.5	81.0	86.5
Range	68-92	67-95	73-100
Oral presentation			
	2013	**2012**	**2011**
Mean	77.6	77.5	82.0
Standard deviation	10.2	8.9	9.7
Median	78.0	78.0	82.8
Range	42-95	55-96.5	60-100

Journal article ^ *			
	2013	**2012**	**2011**
Mean	71.2	71.2	71.0
Standard deviation	10.8	11.8	11.6
Median	72.0	73.0	72.0
Range	35-94.5	42-96	26-93

Student feedback

La Trobe University standard subject evaluation surveys were voluntarily completed by students at the end of semester in 2011-2013. These surveys comprise numerical items and an open-ended section which allows students to provide additional comments.

Numerical item scores and open-ended feedback

Table 4 contains the scores from numerical items that relate specifically to the skills that were aligned to the project intended learning outcomes. Results indicate that students were of the opinion that the project helped them to improve their research, critical thinking, writing, speaking, and team work skills. These scores were comparable in 2011 and 2012; in 2013 these questions did not appear in the surveys due to implementation of a new system by our institution.

Table 4: Student evaluations of the opportunities the subject offered for skills development. Scale of 1-5, where 1 = never, 2 = rarely, 3 = sometimes, 4 = usually, and 5 = always. In 2013 these questions did not appear in the surveys due to implementation of a new system by our institution that omitted these items.

	Mean score (± SD)	
Skills	**2012**	**2011**
Research/inquiry skills	4.4 ± 0.6	4.2 ± 0.7
Critical thinking skills	4.3 ± 0.7	4.1 ± 0.8
Writing skills	4.2 ± 0.8	3.9 ± 0.9
Speaking skills	4.2 ± 0.8	3.9 ± 0.9
Team work skills	4.4 ± 0.6	4.4 ± 0.7
Response rate (%)	84.6	88.9

Responses in the open-ended section of the survey were examined for comments specific to the independent research project in 2011-2013. Table 5 shows the themes observed when examining the written feedback as well as representative student quotes relating to each theme. The common themes that emerged from analysis of this feedback are: (1) the independent research project helped students with skill development; (2) the independent research project gave students an idea of what researchers do; (3) students enjoyed the independence offered by the project; and (4) students wanted more teacher intervention throughout the project. Comments relating to these themes were consistently observed in the 2011-2013 surveys.

Table 5: Themes that emerged from student feedback relating to the independent research project, and sample student quotes.

Students were asked to give details of two or three specific aspects of this subject that have contributed most to their learning; the responses are categorised according to the main themes observed
1. The independent research project helped me with skill-development ▪ Writing the journal article – essentially new ground for me ▪ Journal article has been challenging and we learnt many skills ▪ Journal article has really helped me learn how to write a journal article properly ▪ Research project allows for team communication ▪ The independent learning project is an excellent idea, it forces you to think outside the lectures and apply knowledge. Also improves your team working skills. The oral presentation are also a good idea, the more practice the better ▪ The independent research project helped with research skills and working in teams ▪ The independent research project has helped me develop a lot of individual skills = organizational etc
2. The independent research project gave me an understanding of what researchers do ▪ Practicals, & independent research project made you experience what it feels like to set up, and plan our own project ▪ Undertaking our own independent research project provided a huge insight into the role of a researcher ▪ Independent research project gives students a good sense of independence, and teaches skills valuable for future prospects in pursuing research.
3. The independence of the project ▪ IRP [independent research project] was a good idea. Really enjoyed the independence ▪ Independent research project because I get to study what I'm interested in ▪ IRP [independent research project] was a good challenge and stimulating
4. More teacher intervention ▪ More guidance with the independent research project ▪ More discussion and help around IRP [independent research project] ▪ More structure/support in designing independent research methods

Staff observations

The authors of this paper act as curriculum developers, coordinators, and advisors for the independent research project; this gives us the opportunity to observe the implementation of the project first-hand. We, along with advising staff, have observed that students are highly engaged in the project and we found our own involvement as advisors to be a rewarding experience.

Reflection

The implementation of our innovative model of investigative project work over three years has led to a high level of student performance, as well as high levels of student and staff satisfaction. We hypothesise that this is due to a model with a complex scaffold embedded to support students, along with student participation in authentic scientific practises, which together, inspires students to engage in the scientific process and promote learning and skill development.

Investigative project model authenticity

Overall, staff observed a high level of student commitment to the investigative project work. From identification of the research question through to the culminating poster presentations, the students took ownership of their projects and worked with much enthusiasm, dedication, initiative, and creativity. These observations are consistent with student feedback, as students were overwhelmingly of the opinion that they valued the independent research project, and that it helped them to improve their research skills, scientific communication skills, and team work skills. Our observations are in agreement with other investigators who have evaluated upper-level research projects in a variety of fields, as well as large-scale projects that have appraised student perceptions of authentic learning experiences across a range of disciplines (Caspers and Roberts-Kirchhoff 2003; McCune 2009; Robbins et al. 2008; Turner, Wuetheric and Healey 2008; Wiegant et al. 2011). One of the large scale projects, conducted at the University of Glasgow, found that it was particularly important for final-year bioscience students to identify with the role of a scientist to positively influence willingness to engage with their studies. It is interesting to note that this was a requirement of the present project, as well as the other investigative projects in biochemistry, gerontology and advanced cell biology (Caspers and Roberts-Kirchhoff 2003; McCune 2009; Robbins et al. 2008; Wiegant et al. 2011). Indeed, in the present project, students are required to take on the role of a scientist in its entirety, from the determination of a research question and hypothesis, through to the scientific presentations.

A high level of student engagement is reflected in the wide range of interesting and challenging projects that the students devised, in the enthusiastic student-driven data collection sessions, the numerous laboratory bookings outside of class for additional data collection, and the many requests for appointments with the statistics advisor. During the culminating poster presentations the students were remarkably enthusiastic and proud to present their work. The students were also very interested in viewing the other team posters, and this appeared to be independent of the invitation to vote for the best team poster. We are of the opinion that the student-driven experimental design and team autonomy throughout the project, along with an authentic setting including all teams and department staff, was instrumental in creating a poster session with such a positive atmosphere.

Investigative project model scaffold

Team scaffold

Our project model is predicated on the requirement that students work in teams, as most scientists do, throughout all stages of the 12 week project. No single student could complete the project on their own, and this is a characteristic of effectual team assessment tasks (Luckie, Maleszewski, Loznak, and Krha 2004). Team work, a fundamental graduate attribute, was not directly assessed; however, students could not successfully complete this project without developing their existing team work skills and employing these skills appropriately both within their teams and when collaborating with student colleagues. It is likely that the team work scaffold included in the model, that is, guidance on team work best practices and a team forum for communication, assisted students to become members of functional teams. We are also of the opinion that the allocation of marks for team (10%) and individual (25%) work diminishes the likelihood of unrest amongst team members regarding the effects of unequal team member contributions, and therefore helps to promote positive team dynamics.

Advisor support system

The advisor support system is included in the scaffold to ensure that students feel there is appropriate structure, guidance and support, despite the existence of a student-driven project. Student feedback indicates that the advisor support system was effective, although a small number of students indicated that they wanted more staff input. We are of the opinion that the ratio of one advisor to two teams is ideal, as it ensures that staff have the time to develop a rapport with students, and provide advice on experimental design, data collection and analysis, as well as feedback on written drafts. As the subject coordinators, we also observed that two teams per advisor is optimal in terms of coordination efficiency as it became more difficult to communicate with and manage a larger group of staff when advisors were responsible for one team only. In our scaffold, advisors are required to take a ‘hands off’ approach, which can be difficult for the academics and students who are used to more teacher-centred learning environments. To try to prevent issues arising, we make the process clear to students at the beginning of semester and meet with advisors to explain the model and provide them with an advisors’ guide that explains what their expected roles are throughout each week of the project. Also, one of the coordinators is present in each practical class session to lead by example and provide advice to advisors when appropriate. The general consensus from our staff is that advising students who are engaged in independent inquiry is a far more rewarding way to teach; one of our senior staff members found advising student teams in the independent research project to be the best and most rewarding experience of a 30-year academic career. Other authors have reported an initial level of staff discomfort with the introduction of inquiry laboratories, followed by a liberating teaching experience once they become accustomed to the new style (Luckie et al. 2012).

Assessment scaffold

Preliminary evidence based on student assessment scores indicates that team work skills, and visual, oral, and written scientific communication skills were of a very good standard across the three (2011-2013) cohorts. Caspers and Roberts-Kirchhoff (2003) also found that student grades for a written report in the style of a journal article and a poster presentation were relatively high for assessments completed as part of an investigative biochemistry research project. Our student assessment scores are remarkably consistent across the three years, indicating that student performance was of a high standard regardless of variations in the makeup of the student cohort. The consistent scores may also be reflective of a sound scaffold which includes clear and transparent assessment criteria. The student feedback is consistent with the assessment scores as it clearly indicates that the students were of the opinion that the independent research project promoted the development of research and critical thinking skills, along with team work skills, and writing and speaking skills. In the present project, the team poster scores and the oral presentation scores from 2011-2013 were both higher than the marks allocated for the journal article, which may indicate that the journal article is a more difficult task. It could be argued that the writing of a journal article naturally calls on the author to clearly communicate synthesis and evaluation skills more-so than the other two forms of communication. Given that synthesis and evaluation require higher level cognitive thinking, it appears logical that the journal article task would lend itself to lower student scores. It was apparent that the students’ understanding of, and ability to perform statistical analysis, as well as their ability to evaluate results, are areas in need of attention. That students require additional support in these areas is in agreement with other authors (Caspers and Roberts-Kirchhoff 2003; Robbins et al. 2008). Robbins and colleagues (2008) found that students had a lack of mastery with respect to data analysis and interpretation, and Caspers and Roberts-Kirchhoff (2003) similarly found student weakness with the performance of statistical analysis. Thus, we have identified some areas where the scaffold can be expanded to support students with their completion of tasks that require higher level cognitive skills such as synthesis and evaluation; this will be a focus of future iterations of our investigative project model.

An important part of our model's scaffold is the provision of student resources including a manual with detailed assessment guidelines and rubric marking schemes. We created rubrics for the team poster, individual oral presentation, and individual journal article and avail them to students from the start of semester. Seidel and Tanner (2013) argue that the use of rubrics increases student motivation, and making them available throughout the teaching and learning process can make the learning goals, expectations, and criteria for evaluation clear when it is most needed by students. In 2014 we participated in the Australian Innovative Research Universities Academic Calibration Project (Innovative Research Universities 2014) in which an external expert academic reviewed our course materials, and in particular focussed on the independent research project journal article. The reviewer was provided with 12 de-identified examples of students' journal articles, three each in the pass, credit, distinction, and high distinction ranges. Pleasingly the reviewer agreed with 100% of the marks awarded by a range of our examiners. Further, she stated that "the assessment and marking criteria provide the student with a quality document for inclusion in their professional portfolio for subsequent interviews" (personal communication, July 2, 2014). Research is ongoing to investigate the reliability and validity of the rubrics scores.

Challenges of implementing investigative project work

Despite the benefits of the independent research project to student learning and skill development, implementation and coordination of the project has not been without its challenges. From our experience, infrastructure and support services designed to support curriculum, teaching and learning processes most often do not keep pace with the logistical requirements of a changing curriculum. As we transformed the practical classes from largely cookbook-laboratories to investigative project work, we had a greater need for infrastructure services (e.g., library, laboratories, LMS, and presentation spaces with adequate audio-visual capabilities) and support staff (e.g., librarians, technical staff, and information technology staff). On many occasions our requests stretched the limits of available resources and by default we quickly developed skills in areas that typically fall outside the role of an academic. Universities and departments should therefore consider and support staff and resource requirements when implementing such a curriculum.

An additional challenge faced was the matching of background student knowledge and skill level with that required to embark on successful investigative project work. We evaluated the pre-requisite curriculum delivered to our student cohort to determine gaps in the curriculum, and created a pedagogical framework to bridge the gap. Within the capstone curriculum we introduced learning activities where students gained a sound understanding of the scientific method, experimental design, and scientific presentation skills, as well as proficiencies in the conduct of scientific literature searches, the use of laboratory equipment, and functioning as a valued team member. These activities ensure that the student cohort is equipped to take on the challenge of the independent research project.

Conclusions

In summary, we responded to a call by leading biological and life-sciences experts, and changed the way we deliver our advanced human physiology curriculum. The investigative project work was designed to engage students as active participants in the scientific process and foster development of discipline-specific research skills, team work skills, and visual, written and oral communication skills. Preliminary evidence, in the form of student marks, student feedback, and staff observations, indicates that the rigorously-scaffolded model promotes the development of these skills, and as such, helps lead the students into a culture of professional practice. We believe that the model described in this paper could be adapted by academics across a range of science disciplines, and we encourage others to trial it in their curricula.

Acknowledgements

The authors thank Dr. Stuart McDonald, Dr. Tom Samiric and Associate Professor Johannes Schuijers for their feedback on an early draft of this manuscript, and Mr. Philip Burrows for his feedback on the final draft of this manuscript.

References

American Association for the Advancement of Science (AAAS). (2011). Vision and change in undergraduate biology education a call to action. In C. A. Brewer & D. Smith (Eds.). Washington.

Biggs, J., & Tang, C. (2011). *Teaching for quality learning at university* (4th ed.). New York, NY: McGraw-Hill Education.

Bloom, B. S. (Ed.). (1956). *Taxonomy of educational objectives: handbook 1, cognitive domain*. New York: Longman.

Bourne, P. E. (2005). Ten simple rules for getting published. *PLoS Computational Biology, 1*(5), e57. doi: 10.1371/journal.pcbi.0010057

Bourne, P. E. (2007). Ten simple rules for making good oral presentations. *PLoS Computational Biology, 3*(4), e77. doi: 10.1371/journal.pcbi.0030077

Bracher, L. (1998). The process of poster presentation: a valuable learning experience. *Medical Teacher, 20*(6), 552-557.

Caspers, M. L., & Roberts-Kirchhoff, E. S. (2003). An undergraduate biochemistry laboratory course with an emphasis on a research experience. *Biochemistry and Molecular Biology Education, 31*(5), 303-307. doi: 10.1002/bmb.2003.494031050257

Costa, M. J. (2001). Using the separation of poster handouts into sections to develop student skills. *Biochemistry and Molecular Biology Education, 29*(3), 98-100.

DiCarlo, S. E. (2009). Too much content, not enough thinking, and too little FUN! *Advances in Physiology Education, 33*(4), 257-264. doi: 10.1152/advan.00075.2009

Erren, T. C., & Bourne, P. E. (2007). Ten simple rules for a good poster presentation. *PLoS Computational Biology, 3*(5), e102. doi: 10.1371/journal.pcbi.0030102

Felder, R. M., & Brent, R. (1996). Navigating the bumpy road to student-centered instruction. *College Teaching, 44*(2), 43-47. doi: 10.2307/27558762

Hess, G., & Brooks, E. N. (1998). The class poster conference as a teaching tool. *Journal of Natural Resources and Life Sciences Education, 27*, 155-158.

Hess, G., Tosney, K., & Liegel, L. (2009). Creating effective poster presentations: AMEE Guide no. 40. *Medical Teacher, 31*(4), 319-321. doi: 10.1080/01421590902825131

Innovative Research Universities. (2014). Calibration of Academic Judgements. Retrieved March 30, 2014, from http://iru.edu.au/our-activities/projects/calibration-of-academic-judgements.aspx.

Julien, B. L., Lexis, L., Schuijers, J., Samiric, T., & McDonald, S. (2012, 21 December 2012). Using capstones to develop research skills and graduate capabilities: A case study from physiology, *Journal of University Teaching and Learning Practice*. Retrieved from http://ro.uow.edu.au/jutlp/vol9/iss3/6/

Kellogg, R. T. (2008). Training writing skills: a cognitive developmental perspective. *Journal of Writing Research, 1*(1).

Luckie, D. B., Aubry, J. R., Marengo, B. J., Rivkin, A. M., Foos, L. A., & Maleszewski, J. J. (2012). Less teaching, more learning: 10-yr study supports increasing student learning through less coverage and more inquiry. *Advances in Physiology Education, 36*(4), 325-335. doi: 10.1152/advan.00017.2012

Luckie, D. B., Maleszewski, J. J., Loznak, S. D., & Krha, M. (2004). Infusion of collaborative inquiry throughout a biology curriculum increases student learning: a four-year study of “Teams and Streams”. *Advances in Physiology Education, 28*(4), 199-209. doi: 10.1152/advan.00025.2004

Lundstrom, K., & Baker, W. (2009). To give is better than to receive: The benefits of peer review to the reviewer's own writing. *Journal of Second Language Writing, 18*(1), 30-43.

McCune, V. (2009). Final year biosciences students’ willingness to engage: teaching–learning environments, authentic learning experiences and identities. *Studies in Higher Education, 34*(3), 347-361. doi: 10.1080/03075070802597127

Moneyham, L., Ura, D., Ellwood, S., & Bruno, B. (1996). The poster presentation as an educational tool. *Nurse Educator, 21*(4), 45-47.

Rivers, D. B. (2002). Using a course-long theme for inquiry-based laboratories in a comparative physiology course. *Advances in Physiology Education, 26*(4), 317-326. doi: 10.1152/advan.00001.2002

Robbins, E. J., Kinney, J. M., & Kart, C. S. (2008). Promoting active engagement in health research: lessons from an undergraduate gerontology capstone course. *Gerontology & Geriatrics Education, 29*(2), 105-123. doi: 10.1080/02701960802223159

Seidel, S. B., & Tanner, K. D. (2013). "What if students revolt?"—considering student resistance: origins, options, and opportunities for investigation. *CBE-Life Sciences Education, 12*(4), 586-595. doi: 10.1187/cbe-13-09-0190

Smart, K. L., & Csapo, N. (2003). *Team-based learning: promoting classroom collaboration*. Paper presented at the 2003 IACIS Conference, Las Vegas, NV.

The Physiological Society. (2011). Oral communications.   Retrieved 4 February 2014, 2010, from http://www.physoc.org/p12/oral-communications

The Physiological Society. (2013). Information and guidance for authors.   Retrieved 10 November 2013, 2010, from http://jp.physoc.org/site/misc/author.xhtml

Turner, N., Wuetherick, B., & Healey, M. (2008). International perspectives on student awareness, experiences and perceptions of research: implications for academic developers in implementing research-based teaching and learning. *International Journal for Academic Development, 13*(3), 199-211. doi: 10.1080/13601440802242333

Whatley, J. (2009). Ground rules in team projects: findings from a prototype system to support students. *Journal of Information Technology Education*, *8*, 161-176.

Wiegant, F., Scager, K., & Boonstra, J. (2011). An undergraduate course to bridge the gap between textbooks and scientific research. *CBE-Life Sciences Education, 10*(1), 83-94. doi: 10.1187/cbe.10-08-0100