Transformation of Cookbook Practicals into Inquiry Oriented Learning

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Abstract

Educators are being implored to revitalise science teaching by engaging students as active participants in science, encouraging curiosity and linking the classroom to the real world. We introduced a 5-week team-based inquiry oriented learning project into a first-semester advanced human physiology program to replace four stand-alone exercise physiology cookbook laboratories. The project was designed to promote fundamental research skill development (hypotheses, aims, data presentation in the form of graphs, and conclusions) and foster authentic collaboration between students. Student-teams designed simple experiments, collected and statistically analysed data, and presented the results in scientific format. The project significantly ($p<0.05$) increased team participation when compared to the cookbook laboratories. Students received significantly ($p<0.05$) higher scores for subsequently-written aims and conclusions when compared to students who had completed the cookbook laboratories and required less assistance on the skills targeted by the project on a future research project. Students recognise the importance of the project for providing a scaffold for developing scientific research and team work skills. Our model could be used across the scientific field to maintain gains in content-knowledge afforded by cookbook practicals and to develop important skills expected of science graduates to prepare them to solve challenges of the 21st century.

Introduction

Australia's Chief Scientist Professor Ian Chubb (2014) implores science, technology, engineering and mathematics (STEM) educators to "*teach STEM as it is practiced, in ways that engage students, encourage curiosity and reflection, and link classroom topics to the 'real-world'*". In their *Vision and Change* report the American Association for the Advancement of Science (2011) similarly entreats educators to "*engage students as active participants, not passive recipients ….[and] ensure that undergraduate biology courses are active, outcome oriented, inquiry driven, and relevant*". Australian science graduates are expected to have "*acquired a coherent body of knowledge in a particular disciplinary area….[and] some command of the principles, concepts and core knowledge of the discipline area*" (Australian Qualifications Framework Council 2013). Therefore, as educators we are faced with the challenge of promoting process skill development, including critical thinking, communication, and team work (DebBurman 2002), while teaching an appropriate level of content.

We introduced a human physiology capstone curriculum (Julien, Lexis, Schuijers, Samiric and McDonald 2012) which we believe largely strikes a balance between scientific-content delivery and fostering of discipline-specific research skills. The first iteration of the program contained a 4-week module on exercise physiology including practical classes in which students gained experience using laboratory equipment, calculating physiological variables from collected data, and conducting exercise fitness testing. Completion of this module provided our students with prerequisite knowledge and experience needed to enter the Master of Physiotherapy Practice at our institution. This pathway is popular with our students, therefore, it was necessary to continue to provide this opportunity; however the practicals were largely cookbook-format, and not in-line with the recommendations of the Chief Scientist.

The identification of the exercise physiology practicals as insufficiently inquiry-oriented came around the time that we (the authors), as curriculum developers, coordinators, facilitators, and examiners, observed that many students were making simple scientific errors on major assessments at the end of the capstone program. These errors included incorrectly writing aims, hypotheses, and conclusions, and failing to appropriately present scientific information in graphs. While students also had difficulty with tasks associated with the highest levels of cognitive thinking (Bloom 1956) such as synthesising and evaluating research findings, consistent with observations of other educators (Caspers and Roberts-Kirchhoff 2003; Robbins, Kinney and Kart 2008), it was alarming that many students struggled with fundamental skills. Scientists must be able to communicate formally in peer-reviewed research articles and conference presentations (Colthorpe, Rowland and Leach 2013) which requires students to understand and follow a series of rules or conventions. These rules are not always clear to students. Many students associate scientific writing with complicated phrases, long and difficult words, or jargon (Feldman, Anderson and Mangurian 2001). An analysis of the curriculum delivered within the physiology major revealed that students had not been explicitly taught how to write scientifically appropriate hypotheses, aims, and conclusions and to properly format figures.

Many educators have described models of inquiry-oriented laboratory classes they have successfully implemented in physiology (Casotti, Rieser-Danner and Knabb 2008), exercise physiology (Kolkhorst, Mason, DiPasquale, Patterson and Buono 2001), comparative anatomy and physiology (Chaplin 2003), and organismal biology (Myers and Burgess 2003) subjects. Due to the need to cover pathophysiology and pharmacology topics in semester 1, our exercise physiology module could only take place over 5-weeks whereas other models illuminated run over entire semesters, for example, 12 (Chaplin 2003; Myers and Burgess 2003), 13 (Casotti et al. 2008) and 15 (Davis 2002; Kolkhorst et al. 2001) weeks. Other published models also utilise class (lecture or practical) time to explicitly teach students about: scientific process (Chaplin 2003; Kolkhorst et al. 2001), working with data and graphs (Casotti et al. 2008; Chaplin 2003; Davis 2002; Kolkhorst et al. 2001; Myers and Burgess 2003), experimental design (Chaplin 2003; Kolkhorst et al. 2001), statistical analysis (Davis 2002; Myers and Burgess 2003), and how to use equipment (Casotti et al. 2008; Kolkhorst et al. 2001). Our challenge was to devise a model that would allow students to achieve similar outcomes despite limited class time. Other models allow students to engage with highly complex elements of experimental design including hypothesis formation, literature review, randomisation, blinding, controls, and sample size estimation (Myers and Burgess 2003), and require students to read textbooks and primary literature to build their background knowledge and allow them to design unique experiments (Casotti et al. 2008). In our introductory inquiry classes we have purposely stayed away from complex elements of research study design so students can focus their attention on the key aspects of the scientific process where they have displayed deficiencies. Furthermore, as the project classes are not dependent on the exercise physiology content being covered in the module we are not constrained by a need to synchronise the practical and knowledge-based activities unlike other designers (Casotti et al. 2008).

We seized on an opportunity to solve two problems: (1) revise the exercise physiology practicals to increase the level of inquiry and collaboration while maintaining the discipline-specific skill-development inherent in the classes, and (2) to provide students with an opportunity to focus on foundational scientific skills. While the prevailing scientific education literature is of the opinion that acquiring scientific problem-solving skills through open-ended activities is preferable, it is recognised that these activities are only successful in promoting student learning if students are prepared, or if the activity is properly scaffolded (Kirschner, Sweller and Clark 2006). Wang and Coll's (2005) investigation of physics teaching led them to advise educators to create bridging experiments that, while including some instructions, would progressively place more responsibility on students such that they are better able to "conduct experiments like a scientist" (Kirkup and Johnson 2013). We believe the model that we will present in this paper incorporates a strong scaffold to support students through progressive skill-development. The model could be adapted by colleagues in a range of scientific disciplines who are looking to continue to utilise cookbook practicals that impart essential instrumentation and scientific process skills, as well as support attainment of content knowledge in an authentic and inquiry-oriented manner. Such a model may also provide a stepping-stone to subsequent projects in which students have more autonomy.

Research skills project model

Context of the project

The scientific research skills project was introduced in 2014 as part of a 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. 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 level. Student enrolments in the capstone program have ranged from 77-115. The 2014 cohort demographics were similar to the 2011-2013 cohorts (Lexis and Julien 2014). For the purposes of comparison, there were no obvious differences between the cohorts. The scientific research skills project was conducted over the first five weeks of Advanced Human Physiology 1 and was completed in a weekly 3-hour laboratory class, and a weekly 3-hour guided-independent session (Figure 1). The guided-independent session is listed in the official subject timetable, but has no face-to-face classes. The scientific research skills project replaced a series of four cookbook exercise physiology practicals conducted from 2011-2013 (Figure 1). The subject also has 4 x 1-hour lectures per week (live and online) that are independent of the scientific research skills project. Ethical approval was obtained to conduct the student project (FHEC 10/40, 10/41, 10/42, and 10/45) and to publish student grades and student feedback arising from this work (FHEC 12/147 and 12/170).

2011-2013 curriculum: Exercise physiology practicals

From 2011-2013, students participated in four cookbook-style exercise physiology practicals that were embedded in a student-centred context (Figure 1). Students were given a hardcopy manual and for each of the four practicals they were provided with an overview of the topic area, a list of content-focussed intended learning outcomes, a methodology to follow, results section to enter data, and a list of content-focussed questions to be answered before leaving class. In these prescribed practicals students did not design an experiment and write hypotheses and aims, nor did they perform statistics, create graphs, or form conclusions. Given the prescribed nature of these practicals, student learning was sufficiently resourced with the manual provided, along with exercise physiology textbooks. Because of the content-focussed nature of student learning, we did not consider providing students with a resource along the lines of the *How to Do Science guide*. Given that the initial focus of these practicals was to enhance student learning of exercise physiology content, and not to help prepare students for the semester-long independent research project in semester 2, we did not survey the students to determine if they felt well prepared for the independent research project.

2011-2013		Week	2014	
Timetabled practical class	Guided independent session		Timetabled inquiry class	Guided independent session
Team allocation & safety quizzes. Cardiovascular and respiratory responses to isometric and dynamic exercise	Activities related to other assessment tasks	1	Team allocation & safety quizzes. Use of laboratory equipment to collect physiological data and calculate physiological variables	Experimental design assignment
Exercise metabolism	Activities related to other assessment tasks	2	Submaximal and maximal exercise tests	Read the *How to Do Science guide* for tips on writing hypotheses and aims, generating descriptive statistics, and conducting t tests. Design two simple experiments that will generate data requiring statistical analysis via a paired and independent t test, and write the aims and hypotheses for the study
Sub-maximal exercise testing	Activities related to other assessment tasks	3	Student-designed project data collection	Read the *How to Do Science guide* for ideas on how to work with data in Excel to create graphs
Maximal oxygen consumption	Activities related to other assessment tasks	4	Student-designed project data collection	Using the *How to Do Science guide*, generate descriptive statistics on the data collected, conduct paired and independent t tests, and create graphs
		5	Finalise scientific report	Using the *How to Do Science guide*, write conclusions for the two experiments

Figure 1. Overview of the scientific research skills project. Students had 3-hours of timetabled inquiry class time per week and a weekly 3-hour guided-independent session. The 3-hour guided-independent learning block is listed in the official subject timetable but has no face-to-face classes.

Team creation

In the first practical class facilitators established teams of 5-7 members; students were asked to choose a number at random from a concealed container, with the number determining the team allocation. Teams were informed that they had the freedom to work autonomously, and class attendance would not be recorded. Team forums were created on the learning management system (LMS) and students were informed that it was a tool that they could use for team communication, and there were no conditions set by staff on its use. Teams were 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. Students were provided with a team agreement template to use for this process. Facilitators were available during practical classes to assist teams at the students' request. There was an average of 15 teams in 2011-2013.

Safety screening

Students individually completed the Physical Activity Readiness Questionnaire (PAR-Q; Canadian Society for Exercise Physiology 2002) and the health and safety screening recommended by the American College of Sports Medicine (ACSM; 2010) prior to participation in a maximal oxygen consumption ($\dot{V}O_2max$) test. Students completed the screening via a series of LMS quizzes. If students answered "no" to all questions on the PAR-Q, they were cleared to participate in moderate exercise. If students were also classified as "low risk" using the ACSM screening guidelines, they were cleared to participate in a $\dot{V}O_2max$ test. If students were not cleared to participate as an exercise subject, they were encouraged to actively participate in the data collection process, and in team discussions relating to answers to content-related questions.

Practical classes

Over four weeks, and using the provided laboratory manual, students completed four laboratories (topics listed in Figure 1). The practicals were designed to enhance students' ability to use laboratory equipment to collect physiological data and calculate physiological variables, and also to enhance understanding of the exercise physiology content in these topic areas. For each practical, teams collected data on one volunteer subject using a provided method, and then calculated physiological variables from the data, and answered the series of content-related questions. At the completion of the four practicals, students completed a non-supervised individual online test (true or false and short answer) where, based on a case-study scenario, they performed calculations on hypothetical data, and answered content-related questions. This was worth 8% of the subject grade.

2014 curriculum: scientific research skills project

The exercise physiology practicals were replaced with the scientific research skills project in 2014; the goal was to provide students with a module that was student-centred and focussed on attainment of fundamental scientific skills while still allowing them to gain expertise in instrumentation and the gathering, analysis and interpretation of physiological data.

Learning outcomes

The scientific research skills 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 a guided manner. The intended learning outcomes are for students to be able to: (1) Employ well-developed team work skills to manage and organise completion of team-assignments; (2) Design and implement a small research project that demonstrates application of exercise physiology knowledge and technical skills; (3) Predict outcomes of a research project and present these in the form of scientific hypotheses and aims; (4) Present scientific data in effective figure form; and (5) State the outcomes of a research project and present this in the form of scientific conclusions.

Scaffold

The scaffold embedded within the project model provides a support system for large numbers of students that fosters student-centred participation in the scientific process. At the beginning of the project, students are provided with a detailed hard-copy student project guide that contains intended learning outcomes, a timeline for the project, information to assist with use of laboratory equipment, team information including team agreement template, assessment guidelines, pro-forma for the project report that students submit, and a rubric marking scheme (Figure 2). Students are also provided with a *How to Do Science guide* that assists them with all of the phases of the project: experimental design; writing hypotheses, aims, and conclusions; conducting simple statistics; and constructing a scientific graph. The sections focussing on assisting students with writing hypotheses, aims and conclusions include models to follow and examples (Figure 3). To assist with statistical analysis and constructing scientific graphs, students were given detailed instructions for using *Excel* (Microsoft, Cupertino CA) to analyse their data and create the graphs. Annotated figures from published research papers showing important details to include and formatting conventions to follow are also provided. Although students are expected to act independently throughout the project, facilitators (2 per 80 students) are available during class time to provide advice when deemed necessary by the students. Facilitators are also contactable via email and the LMS project forums.

Criterion	5 – Outstanding 95-100% (No faults)	4 – Excellent 80-94.9% (Minor faults that are easily fixed)	3 – Good 70-79.9% (Minor faults that need some work)	2 – Fair to Poor 50-69.9% (Many faults that need extensive work)	1 – Fail <50% (Skills lacking or absent)	Marks
Hypothesis is stated succinctly and accurately.						/9
Aim is stated succinctly and accurately.						/9
Data is included in the form of an appropriately cropped and enlarged 'print screen' or 'cut and paste' of the Excel data used for statistical analysis. Relevant headings with units are included.					Insufficient data	/5
Statistical analysis results are included in the form of both: **1. Appropriately cropped and enlarged 'print-screen' or 'cut and paste' of the descriptive statistics output (including headings and units) with mean and standard deviation values highlighted for each of the 2 groups.** **2. Appropriately cropped and enlarged 'print-screen' or 'cut and paste' of the independent *t* test output with the chosen *P* value highlighted.**					Wrong test selected for this comparison. Missing headings.	/9
Results are presented in graphic form (figure) constructed using appropriate software with values presented as the mean plus or minus the standard deviation. Axes are appropriately labelled with units included. **Statistical significance is clearly identifiable; significance symbols are present on figures when the *P* value is significant.** **Figure captions & legends are concise and accurate.**				No explanation of what data is presented (e.g., mean ± SD). No indication of statistical test result. Significance symbols are absent from figure when the *P* value is significant. Legend(s) missing from figure. SD error bars missing from figure.	Raw data is presented.	/9
Brief, succinct conclusion that is consistent with the hypothesis and aim.						/9

Figure 2. Rubric marking scheme for one team-designed investigation

SUGGESTED FORMAT	EXAMPLES
Hypothesis	
1) X will cause Y to increase. 2) X will cause Y to decrease. 3) ~~X will have no effect on Y.~~ (Try to avoid this!)	1) Exercise will cause heart rate to increase above resting values. 2) Sleep will cause heart rate to decrease below resting levels.
Aim	
1) To determine the effect of X on Y.	1) To determine the effect of exercise on heart rate. 2) To determine the effect of sleep on heart rate.
Conclusion	
1) X caused Y to increase. 2) X caused Y to decrease. 3) X had no effect on Y.	1) Exercise caused heart rate to increase. 2) Sleep caused heart rate to decrease. 3) Carbohydrate loading had no effect on an athlete's 100 metre sprint time.

Figure 3. Suggested format for writing hypotheses, aims and conclusions with examples

Student tasks and assessment

The students begin with learning how to use equipment to collect physiological data, calculate physiological variables and use the skills developed in conjunction with their guided-independent session to design two simple exercise physiology investigations: one that generates data requiring statistical analysis via a paired t test, and one that generates data requiring statistical analysis via an independent t test. Students need to write hypotheses and aims, perform the statistical analysis, and then generate scientific figures. It is made clear to students that they are not expected to design novel experiments or review the literature but to make use of the knowledge and skills developed in weeks 1 and 2. By doing this, the students are still active participants in the scientific process and take ownership of the project. Students did not complete the individual online test at the end of the 2014 module, as this form of assessment was no longer consistent with the intended learning outcomes that had moved away from content-related learning, towards an ability to implement the scientific method and communicate science effectively.

The team-based project report is worth 10% of the subject grade. Students are provided with a report pro-forma that has the following sections to complete for both investigations: hypothesis, aim, method, data, statistical analysis, figure, and conclusion. The expectation is that students will present their work in accordance with the published physiological literature. Figure 4 provides an excerpt from the report pro-forma the students fill in and submit.

Following marking the reports, we found that too many students were still making basic errors in writing hypotheses, aims, and conclusions and in formatting their figures (examples in Figure 5). Therefore, we decided to use this as a learning opportunity and provided detailed written feedback to each team, a sample 100% report, and the opportunity for students to resubmit their reports to improve their grades. This decision was made on the spot and we did not limit the number of resubmissions; in future iterations of the project we will limit the number of resubmissions to one and provide the sample 100% report from the outset.

Team number: Click here to enter text.

Team member names:

Click here to enter text.

EXPERIMENT GENERATING DATA REQUIRING ANALYSIS VIA AN INDEPENDENT *T* TEST

Hypothesis

Click here to enter text.

Aim

Click here to enter text.

Method

Click here to enter text.

Data

[Replace this text with a copy of the Excel data (raw data) used for statistical analysis, including appropriate headings and units; this could be an appropriately cropped and enlarged 'print screen' of the data or a 'cut and paste' of the data from Excel]

Statistical analysis

[Replace this text with a copy of the descriptive statistics output for both groups (including headings) with mean and standard deviation values highlighted for each of the 2 groups (an appropriately cropped and enlarged 'print-screen' or a 'cut and paste')]

[Replace this text with a copy of the independent *t* test output (including heading output) with the *P* value highlighted (an appropriately cropped and enlarged 'print-screen' or cut and paste). If you chose a one-tailed test, justify your decision]

Results

[Replace this text with a graph of the data, including a figure caption/heading and legend]

Conclusion

Click here to enter text.

Figure 4. Excerpt of scientific research skills project report pro-forma. Students complete the fields shown for both of the investigations.

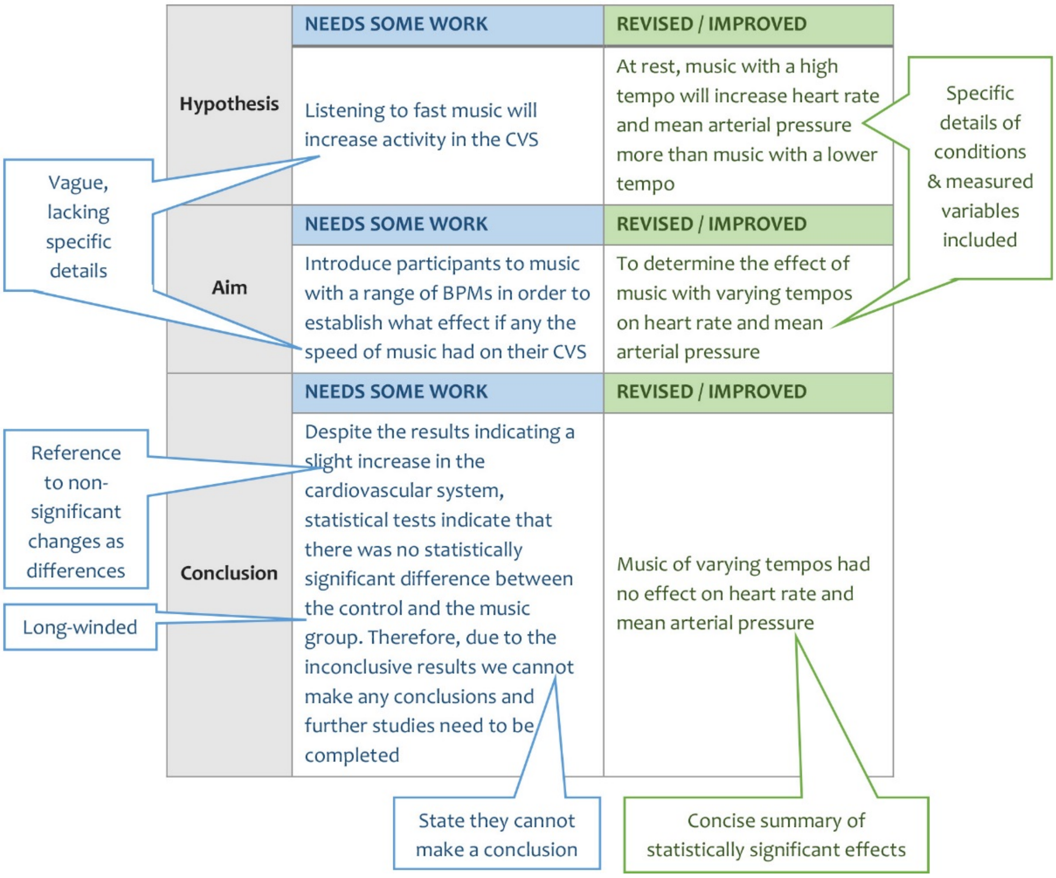

Figure 5. Examples of common mistakes made by students writing hypotheses, aims and conclusions with examples of improvements

Scientific research skills project schedule

Figure 1 provides an overview of the scientific research skills project.

WEEK 1

Inquiry class

Team creation processes and safety screening are completed in the same manner as for the exercise physiology practicals conducted 2011-2013. Students that were not cleared to safely participate in exercise were encouraged to take on a leading role in the implementation of the protocol and data collection. There were 13 teams in 2014.

Using laboratory equipment to collect physiological data and calculate physiological variables

A suggested guided-activity was created to step the students through the process of learning how to use laboratory equipment (Douglas bag system for collecting expired gas, gas analysers, heart rate monitors) to obtain physiological data (heart rate, breathing frequency, fraction of expired oxygen, fraction of expired carbon dioxide, and ventilation [ambient temperature and pressure saturated, ATPS]), and calculate physiological variables: ventilation [body temperature and pressure saturated, BTPS] and tidal volume BTPS, oxygen consumption (absolute and relative) [standard temperature and pressure dry, STPD], carbon dioxide production (absolute) STPD, METS, and energy expenditure. This activity is similar to the first two practicals pre-2014, however, there are no content-related questions for students to complete, and the focus of the activity is for students to become proficient with the use of laboratory equipment so they are prepared to design and conduct their own small exercise physiology research project.

Guided-independent session

Online experimental design assignment

Students complete an online assignment with a series of questions (true or false, multiple choice, and short answer) based on the journal article "Teaching simple experimental design to undergraduates: do your students understand the basics?" by Hiebert (2007). Students have unlimited attempts and unlimited time to work on the quiz during the week that it is open. The assignment is designed to enhance the students' understanding of experimental design in preparation for designing their research project in week 2.

WEEK 2

Inquiry class

Submaximal and maximal exercise testing

A guided-activity was created to step the students through the process of learning how to conduct a submaximal test on a cycle and treadmill, and using heart rate data collected, predict $\dot{V}O_2max$ (Powers and Howley 2012). Another guided-activity was created to step the students through the process of conducting a $\dot{V}O_2max$ test on a treadmill and/or cycle ergometer (Powers and Howley 2012). This activity is similar to the third and fourth 2011-2013 practicals, however, there are no content-related questions for students to complete, and the focus of the activity is for students to become proficient with the use of laboratory equipment so they will be prepared to design and conduct their own small exercise physiology research project.

Guided-independent session

See Figure 1 for a list of student activities carried out in week 2 of the project. Activities are designed to build upon the activity completed in week 1 such that students will have the knowledge and skills to design two simple exercise physiology experiments that generate data requiring statistical analysis via paired and independent t tests (Table 1).

Table 1. Summary of student-designed project topics

Effect of exercise intensity on physiological variables (heart rate, respiration rate, mean arterial pressure)
Differences in physiological variables (heart rate, respiration rate, maximum oxygen consumption, recovery time) between males and females
Level of agreement between predicted and measured maximal oxygen consumption values
Differences in physiological variables (heart rate, respiration rate, maximum oxygen consumption, recovery time) measured following exercise based on treadmill and cycle ergometer protocols

WEEKS 3 &4

Inquiry classes

Data collection

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.

Guided-independent sessions

See Figure 1 for a description of student activities carried out in weeks 3 and 4. Activities are designed to build upon those already completed such that students will have the knowledge and skills to conduct statistical analysis on the data collected, and create scientific graphs.

WEEK 5

Activities for week five in both the inquiry class and guided independent session are focussed on completion of the provided project report pro-forma.

Marking and assessment protocols

Marking of the written reports is completed by staff facilitators using the rubric marking scheme. All facilitators are trained scientists who have experience in presenting at scientific conferences and preparing manuscripts for publication as well as supervision of honours students.

Measurements

Team participation

Team participation outside of class time was determined by the average number of team forum posts on the LMS during the exercise physiology practicals in 2013 and the scientific research skills project in 2014. There were no other team activities occurring concurrently in 2013 or 2014. The assumption made here is that student posts are an indicator of student participation, and student participation is an important predictor of engagement and student success (Beer, Clark and Jones 2010). The content of the posts was analysed and each post was categorised into one of the following themes: team agreements, student illness, team meetings, aims/hypotheses/conclusions, methods, data analysis, data presentation, and generic project.

Scientific research skills project performance

Performance on the scientific research skills project was analysed, along with the number of submissions made by each team.

Ability to write an aim, hypothesis and conclusion

Students' ability to write an aim, hypothesis and conclusion was determined by evaluation of these discrete individual tasks in the semester 2 independent research project oral presentation slides. The scientific research skills project marking scheme was used to mark these items. Scores for these tasks in 2013 were compared with scores in 2014.

Ability to construct a scientific figure

Students' ability to construct a scientific figure was determined by evaluation of this discrete individual task in the semester 2 independent research project journal article. Scores for this task in 2013 were compared with scores in 2014.

Student perceptions of the importance of the scientific research skills project upon its completion

At the completion of the scientific research skills project in semester 1 students voluntarily completed a survey comprising numerical items rating the importance of the project for helping them develop a number of specific research skills. An open-ended question was included which gave students the opportunity to comment on their overall impressions of the project. Responses in the open-ended section of the survey were examined for themes and examples of student quotes relating to each theme were selected for illustrative purposes.

Student perceptions of the scientific research skills project upon completion of the follow-up semester-long independent research project

At the completion of the larger semester-long independent research project in semester 2, students voluntarily completed a survey in which they were asked to comment on the importance of the scientific research skills project in semester 1 as preparation for the independent research project. Responses were examined for themes and examples of student quotes relating to each theme were selected for illustrative purposes.

Staff observations

At the end of the independent research project in semester 2, academic staff who acted as project advisors voluntarily completed a survey comprising numerical items rating the amount of support they were required to give students in 2014 compared to 2011-2013.

Statistical analysis

Comparisons between groups for the dependent variables (forum posts, aim, hypothesis, conclusion and scientific figure scores) were made by independent t-tests. Significance was established at the 95% confidence level ($p \leq 0.05$). All data are shown as the mean ± SD

Results

Team participation

Team participation, as determined by the average number of forum posts per team was significantly ($p = 0.004$) higher in the scientific research skills project in 2014 (21.1 ± 6.1 posts) when compared to the practicals in 2013 (1.2 ± 0.4 posts). Comparisons between groups for topic themes are presented in Table 2.

Table 2. Comparison between the 2013 and 2014 cohort's team forum discussion themes. Values are means ± SD. *Significantly different from 2013 cohort values

Discussion theme	Number of individual team posts 2013	Number of individual team posts 2014	P value
Team agreements	0 ± 0	0.46 ± 0.88	0.07
Student illness	0.15 ± 0.38	0.46 ± 0.88	0.26
Team meetings	0 ± 0	2.31 ± 4.70	0.09
Aim / hypotheses / conclusions	0 ± 0	1.85 ± 2.82*	0.03
Methods	0 ± 0	0.54 ± 1.13	0.09
Data analysis	0.15 ± 0.55	4.46 ± 7.41 *	0.05
Data presentation	0 ± 0	0.77 ± 1.30 *	0.04
Generic project	0.15 ± 0.55	8.85 ± 11.92 *	0.02

Scientific research skills project performance

The average final team score (out of 100) for the scientific research skills project report was 95 ± 6.4. All teams submitted their report a minimum of two times; three teams submitted their project report four times, four teams submitted three times, and six teams submitted twice.

Ability to write an aim, hypothesis and conclusion

Students who completed the scientific research skills project in 2014 received significantly higher scores ($p<0.05$) for their ability to write an aim and conclusion when compared to students who completed the cook-book laboratories in 2013. There were no significant differences (p>0.05) in the students' ability to write a hypothesis when comparing the 2013 and 2014 cohorts. Results are presented in Table 3.

Table 3. Student performance on writing and data presentation tasks

Item	Mean score (%) 2013	Mean score (%) 2014	P value
Hypothesis	80 ± 32	82 ± 28	0.73
Aim	62 ± 38	90 ± 23	<0.001
Figure	65 ± 2.6	69 ± 2.3	0.53
Conclusion	12 ± 28	34 ± 39	0.001

Ability to construct a scientific figure

There was no significant differences (p>0.05) in the students' ability to construct a figure, when comparing the 2013 and 2014 cohorts. Results are presented in Table 3.

Student perceptions of the importance of the scientific research skills project upon its completion

Table 4 contains the scores from numerical items that relate to each of the skills targeted in the scientific research skills project. At the completion of the scientific research skills project students were of the opinion that the scientific research skills project had helped them to develop a range of scientific research skills. Open-ended responses fit into two themes: students enjoyed the project classes and felt well-supported by the facilitating staff, and the project assisted with research skill-development. Examples of student comments for each theme are presented in Table 5.

Table 4. Student evaluations of the importance of the scientific research skills project for skill development. Scale of 1-4, where 1 = not at all, 2 = a little, 3 = somewhat, and 4 = very much

How much did the scientific research skills project help you to:	Mean score (/4)
Complete a team work agreement	3.04 ± 0.92
Work as a valued team member	3.57 ± 0.58
Use laboratory equipment to obtain physiological data	3.56 ± 0.70
Write a hypothesis for a research project	3.56 ± 0.67
Write an aim for a research project	3.52 ± 0.71
Design a simple experiment	3.62 ± 0.60
Organise and work with data in Excel spreadsheets	3.52 ± 0.54
Calculate specified physiological variables from the data	3.52 ± 0.58
Calculate descriptive statistics for a data set using Excel software	3.50 ± 0.65
Conduct an independent t test using Excel software	3.42 ± 0.78
Conduct a paired t test using Excel software	3.50 ± 0.65
Analyse a graph	3.40 ± 0.70
Create and format a graph using Excel software	3.46 ± 0.71
Write a conclusion for a research project	3.40 ± 0.86
To what extent did the research skills project allow you to demonstrate your skill-development and learning?	3.20 ± 0.67

Table 5. Themes that emerged from student feedback on perceived importance of the scientific research skills project upon its completion, and sample student quotes

1. *Students were engaged in the project and felt well-supported*
   - They [inquiry sessions] were fun. Very important to be able to ask questions face to face to [facilitators] when I got confused
   - Really enjoyed the pracs; facilitators were approachable and always willing to help/further help you understand
   - The time given to complete was very ample did not feel pressured to complete the task what so ever
   - Resubmitting the scientific research skills project helped me to understand the format of the paper
2. *Project helped with research skill development*
   - Allowed skills and enforced knowledge from lectures and to see it in practice
   - Very helpful to help me design my own experiment for further study
   - it helped clarify what was necessary. Therefore, a lot more simple than I originally expected

Student perceptions of the scientific research skills project upon completion of the follow-up semester-long independent research project

Results indicate that students were overwhelmingly of the opinion that the scientific research skills project was a valuable project to complete: 82% of respondents (50 students) reported that the scientific research skills project prepared them for the independent research project, 6% said it somewhat prepared them, and 12% reported that it did not prepare them.

The students who believed the project helped prepare them for embarking on the independent research project thought it did so by: providing a scaffold for learning and skill development, improving their research skills, and improving their ability to work as a functional member of a team. Table 6 presents representative student quotes relating to student perceptions of the importance of the scientific research skills project as preparation for the independent research project. The students who did not think the project helped to prepare them for the independent research project focussed on the team work aspect of their experiences and were of the opinion that team work conducted in previous years at university sufficiently prepared them, including (paradoxically) relationship building that occurred in semester 1 of the capstone program.

Table 6. Themes that emerged from student feedback on perceived importance of the scientific research skills project upon completion of the follow-up semester-long independent research project, and sample student quotes

1. *Research skill development*
   - Helped us prepare for the independent research project because it taught us how to present data, and how to statistically analyse data
   - Allowed us to familiarise ourselves with the physiology lab and the equipment available. Also, the project in semester 1 helped us to understand the assignment in semester 2, specifically in terms of the methodology behind designing and conducting a research project
   - I was able to carry out a statistical test and check if my group members did it right. I was also able to translate the numbers into an actual discussion (i.e. p value and significance). I was also able to help out writing a detailed, yet to the point, aim and hypothesis. I was able to use scientific language without using a lot of jargon – which I learned from last semester. The How to Do Science guide was very helpful.

- It definitely set us up well, given that a lot of the skills transferred. It gave us a good grounding, particularly in the statistical analysis section

2. *Team dynamics*
   - It helped me as an individual to work better as a member of a team. Through trial and error I learnt ways to interact better with other members of the group
   - Both involved having good team work skills such as goal setting, team member roles, communication between one another and participation from everyone in the team where everyone gets their say
   - We were able to allocate tasks efficiently as everyone's confidence levels were higher compared to semester 1. I also understood how frequent communication was important for completing tasks so I encouraged the team to maintain this. My communication experience in this team was improved compared to last semester
   - In semester 1 our group didn't work as well together and some members had to do more work than others. Since we put that in our team agreement this semester there seemed to be no problems
   - I was the flakey team member in semester 1 and I refused to be that person again. I am also growing more comfortable with the role of leader, which I seem to end up doing quite a bit

3. *Scaffold*
   - Provided a foundation, and a scaffolding to help design our experiment
   - Guided us through the process that you need to take when performing a research project
   - last semester could be viewed as a 'practice round' as this semester was found to be exceptionally harder than the assessment task set out by the staff last semester. Having this extra experience under my belt I felt as though I was better prepared for what was to come in semester 2

Staff observations

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

Three out of seven (43%) semester 2 independent research project advisors completed the voluntary survey at the end of semester and the results indicate that advisors were asked for less help with skills introduced in the scientific research skills project in 2014 than in previous years (Table 7).

Table 7. Academic independent research project advisor evaluation of the level of support required by students to complete their project. Scale of 1-5, where 1 = much less, 2 = somewhat less, 3= about the same, 4 = somewhat more, and 5 = much more

How much were you contacted in 2014 (compared to past years) by your team(s) regarding:	Mean score (/5)
How to design their study	2.00 ± 1.00
Conducting data analysis (collating, organising data; descriptive statistics)	2.00 ± 1.00
How to conduct statistical analysis	1.67 ± 1.15
How to create graphs / tables to present their data	1.67 ± 1.15

Discussion

In this paper we show how four stand-alone cookbook laboratories were transformed into a single entity authentic project that not only promotes development of skills in physiological data collection and acquisition of content knowledge, but builds on a range of scientific proficiencies such as experiment design, the writing of an aim, hypothesis and conclusion, statistical analysis, and scientific presentation in the form of scientific figures.

Team participation

Team participation on a voluntary basis, as determined by overall interaction on the team forums, was 18-fold higher during the scientific research skills project in 2014 when compared to the cookbook laboratories in 2013. Furthermore, there were more team posts on the topics of writing aims, hypotheses and conclusions, as well as data analysis and data presentation in 2014, when compared to 2013. This was pleasing, given that an important focus of the scientific research skills project was to enhance these skills in students. A recent study by Beer et al. (2010) explored how data captured by learning management systems could be used by academics for measuring, informing and improving student engagement. Whilst research in this area is still in its infancy, Beer and colleagues (2010) suggest that student participation in the online learning management systems may be used as an indicator of student engagement. These authors showed a correlation between engagement, as indicated by clicks of the mouse within the learning management system, and academic achievement as indicated by grade. Using this line of thinking, it is reasonable to suggest that there was increased team engagement in the 2014 cohort, when compared to the 2013 cohort.

The increased team participation in the scientific research skills project may be due to the difference in the nature of the project compared to the stand-alone laboratories. The laboratories consisted of four discrete practical activities, and students generally had time to complete data collection and the content-related questions during class time. In contrast, because the scientific research skills project was a complete authentic project with interconnected parts, teams finished the inquiry class with follow-up tasks that needed to be completed to progress the project. It is logical to assume that this would promote communication amongst team members outside of class, and is a positive outcome of the project given that the biological and life-sciences are collaborative scientific disciplines (American Association for the Advancement of Science 2011). Quantitative and qualitative student feedback undoubtedly shows that students believe that the project helped them to develop skills that enabled them to function as a valued team member. Our observations are in agreement with other investigators who have evaluated research projects in a variety of fields, as well as large-scale studies 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 studies, 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 (McCune 2009). 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).

Research skills

The findings of the present study indicate that the scientific research skills project promoted development of students' research skills. Quantitative and qualitative student feedback shows that student opinion was in agreement with the performance data at the completion of the scientific research skills project, and remained so at the completion of the follow-up semester-long independent research project. Students' ability to write an aim and conclusion, as determined by performance in the independent research project oral presentation slides, increased by 28 and 22 marks (out of 100), respectively. This increased the mean score for the ability to write an aim from a C-level grade (exemplified by the "needs some work" samples in Figure 5) to an A-level grade (exemplified by the "revised /improved" samples in Figure 5). Despite an increase of 22 marks for the ability to write a conclusion, the mean score remained in the fail range. This is a concern, and it appears that the simplicity and brevity of a scientific conclusion may be confusing for students, as a major reason explaining the low marks is that the typical conclusion was long-winded and vague. A priority in future iterations of the scientific research skills project will be to communicate this more effectively to students. The ability to write a hypothesis (also determined from the oral presentation slides) and construct a scientific graph (determined by scientific figures presented in the independent research project journal article) remained unchanged, with mean scores for hypotheses in the A-level grade, and scientific figures in the C-level grade. Despite no change in the mean score awarded for presentation of a scientific figure, advisors for the independent research project reported that they received fewer requests for student help with collating data, performing descriptive statistics, conducting statistical analysis, and creating scientific figures in 2014 when compared to 2011-2013. All of these tasks are integral to the creation of a scientific figure and indicate that the students had developed these skills in semester 1, albeit with room for improvement. Advisors also report that student teams requested less help with the design of their experiment for the independent research project in 2014 when compared to 2011-2013, indicating that the scientific research skills project also assisted with skill development in this area.

Our findings are in agreement with other researchers who show that inquiry oriented learning in an authentic setting fosters the development of discipline-specific research skills. Final-year health science students designed and created their own research project investigating ethnic disparities in the management of diabetes, and working in teams, created a team poster and presentation (Robbins et al. 2008). The findings of this study showed that students demonstrated a significant increase in their knowledge, as well as perceptions of their research skills (Robbins et al. 2008). Rivers (2002) reported on a project-oriented laboratory introduced to 24 upper-level undergraduate students studying comparative animal physiology. Over the course of a 14-week semester student teams designed and implemented a series of small and open-ended projects which culminated in a team poster. These inquiry-based laboratories promoted the development of critical analysis skills and the ability to apply knowledge to solve unfamiliar problems. Wiegant and colleagues (2011) developed an advanced cell biology course at the upper-undergraduate level with an authentic assignment that focused on writing and defending a research proposal. The authentic learning environment strongly engaged students to become self-directed and critical thinkers. A point of difference between our study, and those of the researchers previously described, is that the scientific research skills project focussed specifically on the ability to design a simple experiment, write an aim, hypothesis, and conclusion, statistically analyse data and present results in the form of a scientific figure.

Scaffold to support authentic investigation by student scientists

The scaffold was designed to ensure students felt that there was appropriate structure, guidance and support, despite the existence of a student-driven project, and we are of the opinion that it is critical to the success of the project. Indeed, it has been reported that students can become anxious in situations when teaching styles are excessively student-centred, and lack organisation, direction and support (Felder and Brent 1996). The scaffold is complex and multi-faceted and consists of the student guide, the *How to Do Science guide*, and facilitator presence.

While the prevailing literature promotes the use of open-ended activities in science education, it is recognised that these activities are only successful in promoting student learning if the activity is properly scaffolded (Kirschner et al. 2006). Indeed, one of the major themes arising from analysis of the student qualitative feedback was the recognition that the scientific research skills project provided a scaffold for learning and skill development, and was described by students in the following ways: “guided us”, “a foundation, and a scaffolding”, “a practice round”, and “extra experience”. Student feedback also indicated that the students had gained a great deal of confidence in their ability to conduct scientific research and act as a valued member of a team. Improved student confidence as a result of inquiry oriented learning is consistent with the findings of Robbins and colleagues (2008) who showed that investigative project work improved student perceptions of their research skills.

Resource-based teaching and learning

The student project guide and the *How to Do Science guide* provide a system of resource-based teaching and learning. Resource-based learning supports students’ active and independent study, as it allows learners to choose their own learning path (Esch 2008; Esch and Zahner 2000; University of Technology 2012; Zahner, Fauverge and Wong 2000). For example, students can access the *How to Do Science guide* at the time they need help with processes such as statistical analysis, or the steps involved in creation of scientific figures, and not when a given class is scheduled or when the facilitator has time to explain this outside of class time. Thus, the resource-based learning and teaching style helps shift the relationship between teacher and student towards the realm of colleagues rather than transmitter and receiver of information, respectively (Esch 2008). In support of the literature, the *How to Do Science guide* was viewed by students as a resource that promoted autonomy over learning and this is reflected in the qualitative student feedback. One student informed us in person that: “The *How* *to Do Science guide* is God". Although development of the resources took a substantial amount of time, it meant that in addition to promoting independent learning, the scientific research skills project could run effectively with a ratio of two staff members to 80 students. The project is now set-up to cater for large upcoming student cohorts, notwithstanding the typical updates to curriculum that should be occurring on a regular basis.

Facilitator support system

Another key feature of the scaffold is the facilitator input, and although we did not explicitly ask students to comment on this, many noted that having the facilitators present in inquiry classes was very important when they became confused. We made a concerted effort not to insert ourselves into the team dynamics during class time, and to stand back and let the students take the lead and approach us when they deemed it necessary. It is pleasing to note that the students found this style helpful and didn't interpret the dynamic as 'stand-offish'. As facilitators we found the experience to be very rewarding, as we were working with the students more as colleagues, and this helped us to foster relationships that lasted throughout the rest of the year. There were many occasions when students could clearly see that we, even as trained scientists, did not have an immediate answer to their question. The answer was often generated after a quick Google search, staff-to-staff discussion, or staff-to-student discussion, and these are examples of real science in action. A final comment on the facilitator scaffold was allowing teams to re-submit their reports multiple times. We thought it was important for students to be given some freedom to build upon their knowledge base and skill level, and this was an opportunity that teams took-up and was certainly seen as a positive aspect by the students.

Updates to the scaffold

Because this was an inquiry oriented project, as educators we wanted to guide the students, and not tell them what they had to do. For this reason, we provided them with a *suggested schedule* for the first two weeks of class where they would learn how to use equipment, collect data, and calculate relevant physiological variables. It became apparent that these new third year students were accustomed to being told at the beginning of class what they would be doing for the session. As a result, a number of students interpreted this as an optional but not necessary activity, and consequently struggled during data collection for the actual project. To address this issue we have updated the student guide such that class data collected in the first two weeks of the project will be used to generate scientific tables. This was included to teach the students how to collate data and generate scientific tables which are included in the report that is submitted at the completion of the project. This process also ensures that students are competent using the relevant laboratory equipment.

Conclusions

In summary, we transformed four cookbook practical activities into a research project that promotes team participation and the development of research skills. Students clearly recognised the importance of the project in providing a scaffold for learning, and developing team work and scientific research skills. The approach described in this model could be used in a variety of scientific disciplines, to maintain the gains in content-knowledge afforded by cookbook practicals, but also to develop these important skills expected of all science graduates such that they are more prepared to solve the scientific challenges of the 21st century.

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