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The Coffee Project Revisited: Teaching Research Skills to Forensic Chemists

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ABSTRACT

This study describes a new module design for teaching research skills to analytical chemists based on the use of a student-led, in-class experiment involving coffee. The module was redesigned in response to feedback from students, and aims to give them the skills they need to be productive in future research projects both within the institution and beyond. Over the course of 10 weeks, postgraduate MSc students at the University of Glasgow design, carry out and write up an experiment to determine the effect of pH on the perceived taste of coffee. The module is structured to introduce students to key concepts in research such as experimental design, health & safety, ethics and bias, which the students incorporate into their final experimental protocol. Evaluations of the module for the 2015–16 academic year were positive, and questionnaire data on the participants' self-efficacy with certain research tasks showed an overall increase across the range of skills covered during the module.

GRAPHICAL ABSTRACT

KEYWORDS

Graduate education/research, analytical chemistry, food science, pH, hands-on learning/manipulatives

INTRODUCTION

Students who learn to design and execute experiments are better prepared for postgraduate research and other careers in science.[1] Research-based experiments have also been shown to impart a greater understanding of the nature of science to students, compared to traditional teaching experiments,[2] and research experiences are thought to increase both retention and graduation rates.[3]

Traditionally, students developed their research skills during a placement or project in an academic research group *via* a kind of peer-guided osmosis.[4] However, students can often find this experience daunting,[5] particularly when it does not provide sufficient time or instruction for them to gain the necessary skills to carry out and report an original research project.[6] In response to this, there has been a move in recent years towards introducing research skills beforehand in a formalised classroom setting.[1] These research skills courses are designed to prepare students by introducing them to common research techniques,[7] as well as familiarising students from different cultural backgrounds with research practices in their current environment.

The MSc in Forensic Toxicology at the University of Glasgow is a 12-month full-time postgraduate taught programme, which places a heavy emphasis on analytical chemistry. As part of the MSc, students are required to complete a 20-credit module called *Research & Laboratory Management* (RLM). This course is intended to prepare the students for a summer project in the department, and inspire them to continue with future postgraduate research. The intended learning outcomes for the module are given in Box 1.

Box 1. Intended learning outcomes for RLM

On successful completion of this module students are expected to be able to:

- plan and manage a research project, including drawing up a Gantt chart and budget;
- critically assess and summarise the literature within a specific field;
- identify and develop the use of appropriate research techniques, including a health & safety dimension;
- work collaboratively in a group to design, carry out and evaluate an experiment;
- discuss the ethical and bias implications of the experiment; and
- present the results in the form of an individual poster and journal article, including appropriate statistical analyses.

Prior to the 2015–16 academic year, the RLM module covered topics relevant to research planning (*e.g.*, health & safety, budgeting, *etc.*) but relied heavily on memorisation of material, while providing little active, relevant engagement to reinforce or apply the concepts.[8] In addition, whilst some 'soft' skills (such as experimental design) were taught on the course, acquiring these skills was not specifically rewarded or assessed, leading to a reduced importance in the eyes of the students.[1,9,10] Some key research skills were also missing from the module (*e.g.*, scientific writing) and this was evident in the MSc theses produced by students from previous cohorts, with many making the same basic scientific writing errors. Feedback from the students on the module, by means of standard end-of-semester evaluation forms, was poor, and engagement by the students with the module content was observed to be low by instructors. Students also raised concerns that as the module was heavily information-centric, it was therefore poorly aligned with the applied nature of their forthcoming summer research projects in the department.

The aim of this practice-led project was to design a new applied module based on the existing RLM content, but taking into account student feedback. A description of the curriculum, the assessment criteria used, and evaluation results from implementation of the new module are presented.

This study builds on previous research skills courses reported in the literature.[7,11-13] However, whilst the focus of many previous studies has been on undergraduate students, the study described here involves postgraduate taught students. This population of students is diverse in terms of age, language, culture, and undergraduate degree subject background, providing opportunities for sharing knowledge and ideas.[14] Some postgraduate taught students also have previous experience with research projects.

In addition, this research skills course is inexpensive to run, and does not require a laboratory, technical support, or any complex experimental equipment.

METHODS

A review of the constructive alignment across the module was carried out, resulting in numerous changes, including the use of set texts,[15,16] a reduction in overlap with other modules on the MSc programme, and the addition of new topics. The topics covered were based on the original module's content, but expanded to include those from previous similar research (*e.g.*, ethics),[12] set texts, recent professional concerns from the forensic science field (*e.g.*, contextual bias),[17] feedback from students (*e.g.*, writing an MSc thesis), and instructor observation of the group's needs (*e.g.*, scientific writing).

However, the main contribution to the new module was the inclusion of the *Coffee Project*, an idea taken from Mabrouk,[12] where students carry out an in-class experiment to determine the effect of pH on the taste of coffee.

In the original paper, the students carried out the Coffee Project experiment at the end of a research skills and ethics course. The practical element of the Coffee Project (the tasting) was teacher-led and carried out as a group. Each student then used the results as the basis for an individual journal article, which the students went on to peer review.[12]

In this study, the Coffee Project concept was introduced at the start of the 10-week course and was student-led. Students were given the brief: "Design, carry out, and write up an experiment to determine the effect of pH on the perceived taste of coffee" and they planned each element of the experiment as a group over this period.

During each of the module's sessions, students learned about a different research concept (see Table 1) and used it to build up their experimental design. The sessions were designed to help students understand the research process, whilst working in a team environment.[11] Each session started with a brief formative quiz on the assigned set reading. This was followed by a short introductory lecture on that session's topic, and then by assignments to be carried out in small groups (of 3–4).

Each assignment was designed to encourage students to apply that session's content, and also to add another layer to the experimental design of the Coffee Project. At the end of each session the small-group or individual ideas from the assignments were shared with the rest of the class and incorporated into the protocol for the final

experiment. Additional assignments (see Table 1) were completed individually by students outside of class.

A detailed module schedule, similar to that given in Table 1, was distributed to the students in advance. Resources such as lecture handouts, weekly set reading, references from the literature and photographs were made available to students during the module, in this case *via* a virtual learning environment. At the end of the module the students carried out the experiment they had designed as a group and used the results, as before, as the basis for an individually assessed journal article.

Staff actively assisted students throughout the module, providing instruction, facilitating discussion, and giving informal verbal feedback during each session. Formal written feedback was also provided on the assignments completed by students each week (*e.g.*, the literature review, scientific writing tests, *etc.*, see Table 1 for a complete list). However, the design of the final experiment was decided by the students. The peer-review element of the original Coffee Project was not included in this module design.

Table 1. Sessions in the Coffee Project

Session	Title	Content[a]	Key Points for the Coffee Project	Assignment
1	Project planning	Asking the right research questions (critical thinking); Literature reviews (information literacy); Timelines and goals	Relevance, e.g., number of coffee drinkers worldwide; A few background articles provided	Complete a literature review[b] on the different variables that affect the perceived taste of coffee; Prepare a Gantt chart for the Coffee Project
2	Experimental design	Generating hypotheses; Developing a protocol; Controlling variables; Recap of the Nernst equation	Other variables that affect coffee taste, including: origin; coffee blend; brand; brew method; addition of sugar, milk, syrups; water temperature, quality and treatment (roast level) of coffee beans;[18] Measuring taste as a variable, palette cleansing; Volume of coffee required per "taste", need for plain black coffees	Estimate the number of different coffee brands required and produce a list of local coffee shops
3; 12	Writing tests	See Robinson et al.[19] for an example test	Scientific writing skills, including: audience and purpose, writing conventions, grammar and mechanics	—
4	Budgeting	Cost of consumables and equipment	Price of coffees, lab equipment required (pH meter and thermometer)	Devise a budget for the Coffee Project

5	Health and safety	Control of Substances Hazardous to Health (COSHH); Material Safety Data Sheets (MSDS); Risk assessments	Possible hazards for the Coffee Project including: burns/scalds, allergic reactions, electric shock, biological/chemical contamination	Complete a risk assessment for the tasting and a COSHH form for the pH buffers used to calibrate the pH meter
6	Writing a journal article	Content of each section; Polish; Common mistakes	Preparation for the summative journal paper assessment	—
7	Ethical research practice	Ethical approval for experiments; Research misconduct including: fabrication, falsification, plagiarism, assignment of credit, conflicts of interest; Consumer ethics	The ethics of recruiting volunteers to drink coffee, the use of large coffee chain brands, informed consent, data protection	Produce a list of ethical considerations for the Coffee Project; Complete a Univ. of Glasgow ethical approval form for the Coffee Project; Discuss ethical dilemmas from *On Being a Scientist* [20]
8	Bias in research	Bias at different stages of research projects including: recruitment, data analysis, interpretation, publication	Cognitive factors that influence perceived taste of coffee, including: brand, colour of coffee cup;[21] Use of plain paper cups, coding, and random-ization to minimize bias; Tasters not involved in coffee purchases	Produce a list of cognitive factors that may bias the Coffee Project
9	Posters	Level of detail required; Fonts and formatting; Example posters from staff and Ph.D. students used; Tips and guidelines from the university library and Erren and Bourne[22]	—	Design a poster for the Coffee Project (to be printed on A4 paper); Critique previous years' posters at a conference-style event
10	Preliminary experiments	Buy takeaway coffees from local shops, initial pH and temperature measurements; Method validation	Accuracy, precision, and calibration curve determined for the pH meter according to international guidelines[23]	Conduct a pilot study and devise the final experimental protocol
11	Writing an MSc thesis	Organization of text; Content of each section; Referencing; Previous years' theses shown to students	—	—
13	Final experiment	Student-led experimental design	Data collection; Debrief discussion on limitations of the experiment, e.g., variables, subjectivity of taste, ideas for future improvements	Analyze data and write up as an individual journal article

[a]Relevant chapters from the set texts were chosen as preparatory reading. [b]Critical evaluation of a scientific journal article was covered in a previous module.

The journal paper assessment was prepared using a real journal template for a 'Communication' with a three-page limit to encourage concise scientific writing. The criteria given in Box 2 were used to assess the journal paper, with each section given a specific weighting, and grades were awarded using the University of Glasgow's in-house marking scale.

EVALUATION

The ability of the new module to increase students' confidence (or self-efficacy) with certain research tasks was evaluated by means of two questionnaires. Changes in

confidence were examined in this study, as increased confidence has been shown to improve both retention[2] and future performance. Our hypothesis was that students' confidence with certain research tasks would be improved following completion of the module.

Students enrolled in the RLM course during the 2015–16 academic year were eligible to complete the questionnaires and did so on a voluntary basis. Registration for the module was 16. Ethical approval was received from the College of Medical Veterinary and Life Sciences Ethics Committee at the University of Glasgow (project no. 200150028). Participants received an information sheet that summarised the purpose of the project and had an opportunity to ask questions.

Fourteen of the sixteen students taking the module in 2015–16 completed the questionnaires and each signed a consent form. Questionnaires were completed anonymously and stored separately to consent forms. The questionnaires required only tick responses to avoid concerns about handwriting recognition.

Box 2. The marking criteria used to assess the summative journal articles

Overall
Is the paper clearly laid out and sectioned appropriately?
Has the template been used? Is the paper three pages or fewer?
What are the standards of spelling, punctuation and grammar?

Introduction
Is the problem stated?
Is there a hypothesis statement?
Are the aims of the study given?
Is the literature review comprehensive? Does it set up the aims and hypothesis?
Has the correct style been used for citations and the reference list?
Are full bibliographic details given?

Methods
Are the instruments used detailed? Is validation mentioned?
Are procedures described in enough detail to be replicated?
Are ethical and bias issues discussed?

Results
Are appropriate statistics chosen given the nature of the study?
Are tables and figures clear?
Are tables and figures cited appropriately?

Discussion and Conclusion
Are limitations discussed?
Is a justified conclusion given?
Is future work mentioned?

The questionnaire was first administered during the first lecture of the module; it was administered a second time 9 weeks later. Using a scale of 1–5 (with 1 being "not at all", and 5 being "very"), students were asked to characterize their responses to these questionnaire items:

- I feel competent to write a paper for a scientific journal.
- I am comfortable discussing the ethical implications of scientific research.
- I feel competent to write an MSc thesis.
- I feel competent to plan a small scientific research project.
- I am comfortable discussing the concept of bias in scientific research.
- I feel competent to produce a poster for a scientific conference.
- I feel competent to write a risk assessment.

All data were collected in paper format and transferred to MS Excel for analysis. These data were not analysed until the end of the module. The statistical language R was used to analyse the data,[24] and ggplot2 was used to produce data visualisations.[25]

End-of-semester evaluation forms were also given to students at the end of the module, and after the summer projects, as is standard practice. These include a section for free-text comments.

RESULTS

The results of the two questionnaires, shown as a dot plot in Figure 1, show an overall increase in confidence score across all questions, indicating an overall increase in student self-efficacy with research skills after completion of the module. Although few of the students felt 'very' confident (a score of 5) with any of these research skills, most students rated their confidence with a score 3 or 4 across the board at the end of the module, with the most pronounced increase observed for discussing bias. The question on 'Writing an MSc thesis' was answered with a score of 2 by three participants at the end of the module. This likely reflects the fact that this was the only session that did not include an assignment (MSc theses are written at the end of the summer projects) therefore reinforces the importance of active learning.[26] As the data are anonymous, no inference about the self-efficacy of students with different demographics can be made.

The questionnaire data have a number of limitations. Firstly, due to anonymity restrictions associated with ethical approval, these data are not paired. This means it is not possible to conclude whether all participants showed an increase in confidence across all research tasks following completion of the module. Secondly, when completing the final questionnaires, participants may have perceived an expectation from staff that they should now feel more confident and scored their answers accordingly. Thirdly, this data was gathered from a small sample size (albeit with an 88% response rate) and is restricted to a single, specialised MSc cohort.

In terms of module evaluation by staff, one of the authors noted that the module significantly improved their relationship with the students, as well as improving attendance and engagement by students compared to the previous teaching of this module. The standard of scientific writing in the 2015–16 MSc theses was also noted to be improved on previous years by staff.

In addition, as noted above, one of the aims of the RLM module was to inspire students to continue with future postgraduate research, and at the time of writing two of the students from the module have been accepted into PhD programmes.

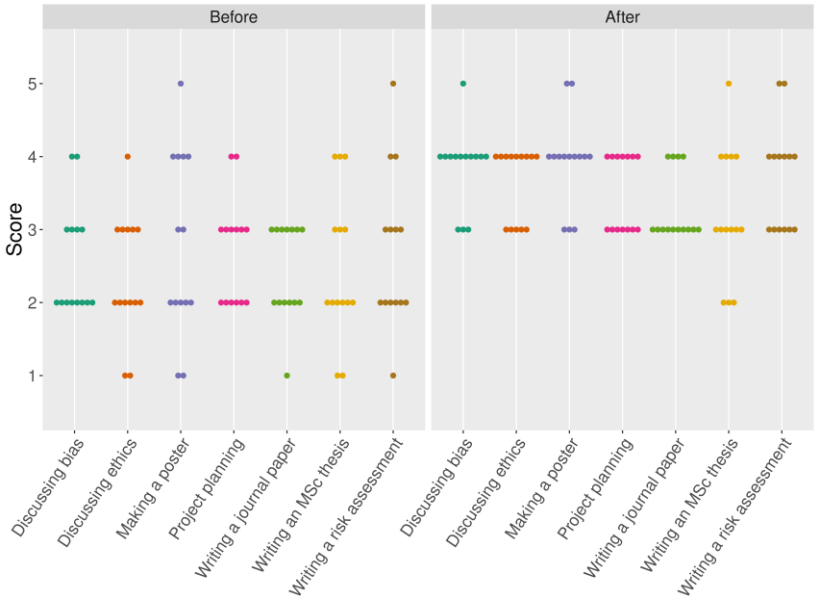

Figure 1. Dot plot showing the answers (N = 14) to the two administrations of the questionnaire used in this study, before and after completion of the module. Students rated their responses to statements on a scale of 1 to 5, with 1 being "not at all", and 5 being "very". Each colour represents a different question. The results show an overall increase in confidence score across the questions asked from before to after completion of the module.

Several students included positive comments regarding the Coffee Project on their standard end-of-semester evaluation forms and at student–staff liaison committee meetings:

"Using the Coffee Project to highlight all the topics of the syllabus was really interesting and useful."

"The Coffee Project helped me to understand the research process – fantastic course to improve my research skills."

"RLM lectures were useful when it came to writing the thesis (help with COSHH forms etc.)."

"Using the Coffee Project made it more interesting than just a series of lectures."

However, some students expressed the concern that too much time had been allocated to the Coffee Project, given that it was only worth 10% of the overall module grade. This likely represents a failing on behalf of the authors to explain to students the purpose of the Coffee Project as a mechanism for improving research skills, rather than as a means of producing data for a summative assessment.

The standard of scientific writing in the assessed journal articles was generally high, with the papers being clearly laid out, and very few of the common writing errors identified in the two writing tests occurring. Sufficient experimental details were provided by the students to allow replication of the protocol, and the figures/tables were generally clear and helpful to the reader. References were appropriate and up-to-date. Although the extent of statistical analyses employed by the students varied, the statistical tests used were appropriate for the dataset, and justified conclusions were drawn. The students made insightful interpretations of the data, and most discussed the limitations and bias implications of their experiment.

DISCUSSION

In this study we aimed to demystify the practice of research by providing students with an authentic and meaningful activity that allowed them to explore the way in which data are generated, analysed and interpreted through experiential learning.[5] The use of the Coffee Project was designed to engage students with a real-life, relevant research topic, and most importantly, to allow the transfer of ownership and control of the learning process to shift from the instructor to the students.[27] The new module emphasises active learning of research concepts, and this resulted in improved

engagement, with students showing more interest and curiosity during the sessions.[5] The Coffee Project also had the advantages of creating stronger alignment between each of the module themes, and giving students the opportunity to apply the new concepts they had acquired through engaging in applied research.[1]

The decision was made to introduce the students to the Coffee Project concept as early as possible, as it has been noted in similar studies that if they do not understand the research goal early on, they are less interested and their work is less focused and efficient.[13] The use of a simple topic with minimal instrumentation meant that the students were not intimidated by the material,[28] nor were they subject to the cognitive overload associated with having to learn new, complex experimental techniques while exploring.[4] This allowed them to focus on understanding the concepts, processes and attributes that underpin the practice of research. In addition, the taste of coffee is a real-life, relevant topic that many of the students were familiar with and interested in.

A detailed module schedule and timetable were distributed to the students in advance. Giving students these details at the start of a course has been observed to enhance student enthusiasm, involvement and learning.[1] The regular feedback provided to students seemed to enhance student–instructor relations, and resulted in improved student motivation, particularly for the quizzes on the set reading. Quizzes based upon the assigned literature were used in a previous study to encourage students to stay up-to-date with required class reading.[4]

The writing tests in sessions 3 and 12 were designed to specifically target a subset of skills needed by students before they write their first journal article, and reflect the fact that students can struggle with academic writing if their previous experience is

limited to lab reports.[13,19] The journal paper assessment using a template from a real publication has been used successfully in previous studies.[29,30] Students had learned to use software such as EndNote for referencing, and ChemDraw to produce publication-quality figures for their articles in a previous module.

This module design employs a collaborative approach to problem-solving both in small groups on regular in-class tasks and discussions, and also during the final whole-class experiment. The ability to work in groups of varying size is important in many workplaces, as well as valuable for conducting postgraduate research.[2,29] The module is run over the course of 10 weeks. This length of time was thought to be important as our traditional laboratory classes involved experiments that could be completed in 2–3 hours, whereas our summer research projects are run over 8–10 weeks.

Future iterations of this teaching method could be improved by either the instructor or peers giving formative feedback on a draft of the journal paper assessment. An additional training session on peer review during the module would help to ensure the quality and reliability of peer comments.[31] Although the journal paper assessment requires the ability to organise raw data into an appropriate format and interpret it in order to reach a conclusion about a hypothesis,[2] this was not covered explicitly in the curriculum. An additional session on evaluating data could now be added using the 2015–16 results as an example dataset. Students could also consider sources of error *e.g.*, taste subjectivity in their experimental design.

This paper outlines a framework for teaching research skills that, in future, could be applied to other beverages, *e.g.*, cola, orange juice, tea, *etc.*, including an element of student choice, if appropriate.

In terms of staffing resources, the module was designed and delivered with the input of just two instructors. The involvement of additional staff would relieve some of the

teaching load, particularly with respect to providing written feedback on regular assignments, and expose the students to a more diverse view of science and research.[6]

Finally, a limitation to this module design is the large number of uncontrolled variables that also affect the perceived taste of coffee (see Table 1 for examples), and their importance relative to pH. In future iterations of this module, students will be encouraged to discuss other taste variables, both before and after their final experiment, so as to identify limitations and opportunities for improvement in their protocol.

CONCLUSION

This article has described a new module for teaching research skills where the students are encouraged to take shared responsibility for an in-class experiment called the Coffee Project. Positive evaluations of the module after the 2015–16 year suggest that the participants found the activity meaningful and relevant for their future research projects. Questionnaire data on the participants' confidence with certain research tasks showed an overall increase in self-efficacy across the range of skills learned during the module.

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