Writing Activities Embedded in Bioscience Laboratory Courses to Change Students' Attitudes and Enhance their Scientific Writing

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We introduced writing activities into a project style third year undergraduate biomolecular science laboratory to assist the students to produce a final report in the form of a journal article. To encourage writing while the experimental work was proceeding, the embedded writing activities required ongoing analysis of experimental data. After formative feedback from peers and teaching staff, the revised work was incorporated directly into the prepared journal framework. Surveys of student attitudes showed significant improvements in confidence in their ability to write an introduction, produce figure legends, distinguish results from discussion and generate a logical flow of information. Attitudes towards report writing became significantly more positive and the training was highly rated. Key factors that contributed to the perceived benefits were use of the student's own data, the chance to incorporate revised work directly into their reports and the realisation that they were performing tasks of direct relevance to their future careers.

Keywords: Interactive Engagement, Science Communication, Student Attitudes, Writing Skills

INTRODUCTION

The ability to present scientific findings in an accurate, informative, coherent and logical manner is a core skill needed by scientists. It can dictate success in publishing journal articles, preparing reports, obtaining grant funding and communicating research findings. At the undergraduate level, instruction in scientific writing as part of a laboratory course can both prepare students for future careers and significantly improve their critical thinking skills (Quitadamo & Kurtz, 2007). Furthermore, the practice of writing regularly, from the beginning of a research project, is advocated as a way to develop, clarify and test ideas while experimental work proceeds (Martin, 2009). The practice of regular writing also fosters creativity (Boice, 1983) and research paper productivity (Boice, 1989).

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One of the challenges in teaching science at University is to provide effective ways to engage the students with scientific communication and promote the writing process as being at least as important as the experimental work. A barrier to these aims is that science students may like experimental work but dislike writing. For example, a survey of 215 introductory biology students at the University of Wisconsin-Madison found that 45% did not like writing even though 98% of the students considered science writing important (Manske, 2010). Whilst students may accept that writing is important for scientific communication in general, their dislike of the writing process can create resistance to inclusion of writing as part of their science training, particularly in laboratory courses.

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State of the literature

- A core skill needed by scientists is the ability to present scientific findings accurately and logically.
- Most University courses include training in writing; however, generic training often fails to instruct students on how to present experimental findings in the style of scientific publications.
- Active production of data, concurrent analysis and interpretation of that data, and ongoing formative feedback enhances student engagement.

Contribution of this paper to the literature

- Writing activities embedded in a laboratory course engaged students in the writing process.
- The activities enhanced students' knowledge of the structure of a paper and brought about positive changes in attitudes towards the writing process and belief in their ability to write scientific publications.
- A contributory factor to their success was the direct relevance of these skills to future careers.
- This paper suggests a simple way to incorporate writing activities into experimental courses to engage students with a communication skill needed by all scientists.

Various strategies to improve writing at University level exist. They include general scientific writing courses (Rice, 1998), University-wide English training programs, such as "EnglishHELP offered by Griffith University (www.griffith.edu.au/griffith-english-language-institute/university-initiatives/englishhelp) and inclusion of some writing as part of all undergraduate courses. The University of Wisconsin-Madison has developed a web site called Writing-Across-the-Curriculum (WAC) that provides discipline-specific writing training for instructors who want to find effective ways to use relevant writing assignments in their courses (http://mendota.english.wisc.edu/~WAC/). Some instructors have created discipline-specific writing-skills exercises that they believe can be adapted for a variety of learning environments and used either for in-class activities or as homework assignments (Robinson, Stoller, Horn, & Grabe, 2009). However, an analysis of the effectiveness of such strategies (Jerde & Taper, 2004) revealed that the number of English composition courses taken, the use of the University's Writing Centre, the year of study, and the completion of "technical" writing programs (designed for engineers, business professionals and scientists) did not significantly enhance their students' scientific writing ability. Prior experience in writing a science research proposal, for which constructive feedback on an outline was provided, was the only factor identified as improving student scientific writing. The authors concluded that scientific writing needs to be integrated directly into specialised courses and that there needs to be instructive interaction between staff and students regarding their writing style.

A further challenge for the instructor wanting to improve students' writing skills is to be able to identify the problems associated with scientific writing as perceived by the students (rather than those assumed by the lecturer) and design tasks accordingly. Most teachers who have assessed typical laboratory reports could list common mistakes such as including information in the wrong subsections, reiterating results in the discussion without interpreting them and failing to correctly produce and label figures (Whelan & Zare, 2003). However, corrective strategies such as provision of clear writing guidelines and examples of poor and good writing may not achieve the desired improvement unless the students embrace the idea of writing, understand the guidelines, learn to apply writing conventions and believe the exercises to have applicability and relevance. Tactics that have been reported to result in significant improvement in report quality (judged subjectively by the authors) (Gragson & Hagen, 2010; Whelan & Zare, 2003) largely followed the suggestions of Jerde and Taper (2004). Their students completed integrated subject-specific exercises, related to laboratory experiments, and received peer and tutor feedback that could be used to improve the journal-style final reports. However, apart from quoting some positive comments made by the students in course evaluations (Gragson & Hagen, 2010), student attitudes to writing were not documented in either study. Other researchers, who incorporated repeated writing assignments and discussion into a biology course, evaluated student attitudes pre- and post-course completion as well as tracking progressive changes in assignment quality (Lauer & Hendrix, 2009). However, the focus of these assignments was manuscript evaluation, concept evaluation, or textbook reading and did not attempt to enhance writing skills required to report experimental data. Although there are many options presented in journal articles that might provide instructors with potentially useful approaches to improve student writing, few reports have assessed student attitudes towards scientific writing before they received subject-specific training and how that training affected their perceptions and confidence when confronted with a writing task.

We present in this paper the strategies that we employed in a final year undergraduate laboratory project at Griffith University, Australia. Our objectives were to improve students' attitudes towards writing and to enhance their written communication skills. The writing activities were not presented as a separate training activity. Instead, the activities were an integral part of the laboratory course. They required the students to use their own data to produce subsections of their final journal-style report, which were checked for their quality by peers and tutors. The feedback was used to improve the quality and the improved subsections formed the models on which the rest of the report could be based.

We also present the changes that occurred in the students' knowledge of and confidence in writing scientific articles as a result of completing the course.

Background to the adoption of in-course writing activities

The Biomolecular Sciences Laboratory course was a project-style laboratory in which students isolated, purified and characterised an enzyme from rabbit skeletal muscle. The style and content of this course suited a requirement, introduced in 2000 by the course convenor (SL), for the students to write up the work in the form of a short scientific paper. To assist the students in this task they were given standard author guidelines from an international journal, with additional accompanying explanation and examples. To encourage rigour in applying the journal guidelines, marks were allocated to categories such as adherence to journal formatting requirements, and the need to provide figures and tables with sufficient detail that they could stand on their own. Although this information improved the standard of presentation, the students always delayed the writing process until after completion of the practical work, and then had little chance for constructive feedback on their ability as scientific writers. There was no formal contact with the teaching team during the production of the paper and feedback was thus limited to comments written on their final manuscripts. Unfortunately most students focus on final marks and fail to see how separate University courses integrate with each other and require similar skills. They therefore failed to apply the feedback received for writing tasks in one course to improve their performance in subsequent courses, rendering the efforts of the staff to give helpful feedback largely wasted.

In 2008, new writing activities were integrated into the experimental phase of the course, so that sections of the students' final papers were effectively being produced concurrently with the practical work. We present below the structure and outcomes of this program of writing activities. The program was implemented in 2008 and repeated in 2009, with slight modifications based on suggestions from the students for further useful activities.

The University context

Griffith University is a large institution, with campuses in Brisbane, Logan and the Gold Coast, and an enrolment of more than 38 000 students from 119 countries. It has internationally recognised strengths in teaching and research. A strategic priority of the University's Academic Plan is to continue to embed work-integrated learning and research-based learning experiences into programs.

The student cohort and learning context

Within the Faculty of Science, Environment, Engineering and Technology, the School of Biomolecular and Physical Sciences (BPS) offers degrees in science, biomolecular and biomedical science, biotechnology, forensic science and aviation.

The Biomolecular Sciences Laboratory was a third year undergraduate laboratory course within the School of BPS. Students enrolled in the course in 2008 and 2009 were from a range of degree programs (Table 1). Most students entering the third year laboratory classes had passed competency-based biotechniques laboratory courses but had little training specifically in reporting experimental work in a style acceptable to journals that publish experimental outcomes. Their previous exposure to scientific communication had been primarily in a first year social studies of science course, with essays specifically suited to that genre.

Table 1. Student enrolments in the course, Biomolecular Sciences Laboratory, in 2008/2009, sorted by Program. The year of study for this course within each program is shown in brackets. Total enrolment was 70 students (38 in 2008 and 32 in 2009).

Number of students	Program
23	B. Biotechnology (3rd year)
18	B. Science (Biochemistry/Molecular biology major; Biological Science/ Chemistry major) (3rd year)
10	B. Biomolecular Science (3rd year)
8	B. Biomedical Science (elective course) (3rd year)
6	B. Forensic Science (2 x 2nd year, 4 x 3rd year)
3	B. Information Technology/B Science (biological sciences major) double degree (4th year)
2	B. Science (Advanced Studies) (Biochemistry/Molecular biology major) (3rd year)

The course was offered over a two week time period, at a time of year that is normally a mid-year holiday period (four weeks) for the students. It was presented in "intensive mode" with students attending from 8.30 am until around 4.30 pm daily for 5 days of laboratory work, integrated writing activities, and short lectures/tutorials. During this time they completed the mini-project to isolate, purify and characterise an enzyme from rabbit skeletal muscle, completed the writing activities and received feedback on their quality from the staff. This was followed by a week in which they independently finalised a short scientific paper describing the work that they had completed.

The laboratory work and the writing activities were supervised by a small team comprising the course convenor/lecturer, PhD students familiar with the project and with some experience in scientific writing, and a research scientist who had developed the writing activities and the accompanying course surveys that evaluated the writing activities project.

METHODS

Purpose of the scientific writing activities

To assist the students with correct interpretation of a journal's guidelines to authors, and production of a concise paper, specific writing activities in addition to the journal's "instruction to authors" were integrated into the course. The writing activities were designed to engage the students, make explicit connections to their intended careers, foster collaborative learning and provide a useful basic model of appropriate scientific writing for the students to apply and extend. Completion of each activity enabled the students to begin construction of their scientific paper whilst performing the experiments, and whilst they had access to the advice of the course convenor and tutors.

Structuring the writing activities to assist student learning

Some writing activities were undertaken during the weekend immediately prior to the week of laboratory work and the remainder were integrated into the daily experimental program. Activities drew on the theoretical background to the experimental work but more importantly on the data being generated by the students. Students completed the writing activities during natural breaks in their experimental work, for example during reaction incubations or during gel electrophoresis. Students could therefore write about their data concurrently with its generation. Feedback from staff during the experimental week was utilised to improve the written work and the completed activities could then be incorporated directly into their paper. Feedback on the entire paper was not provided. Instead, students were given individualised feedback on typical subsections and were then expected to apply the learned principles to similar sections of their paper.

Writing activities issued to the students complemented the standard journal guidelines (with related comments and hints). Each activity had a checklist (Table 2) to be marked off initially by each laboratory partner, before a tutor assessed the quality. The checklist helped to focus the students on the specific requirements for a scientific paper and critical reading of each others' work encouraged collaborative

Table 2. The first of four writing activities designed to help students write a scientific paper. This activity ensured that the students had done some background reading on the project, could cite their readings correctly, and had created the correct framework for their paper.

Preliminary Activities – preparing a Framework and Introduction	Checklist
a: Preparing a framework for the scientific paper *Use a writing program such as Word to organise the pages and headings in your paper as specified in the Journal's instructions to authors*	<u>a:</u> • Does the report contain the headings: Title Page, Abstract, Key Words, Introduction, Methods, Results, Discussion, Acknowledgements, References? • Are the pages numbered on the top right hand side? • Is the font size at least 10; are the lines 1.5 spacing? • Are the margins at least 2 cm?
b: Getting started on the Introduction and References *Under your "Introduction" heading write a very short paragraph to introduce the subject of your research project. It must include at least one reference (use the author/date system and follow instructions for the correct way to cite and list your references)*	<u>b:</u> • Has the author introduced the enzyme of interest? Has the author explained its function and where it is found? Has the author stated the general aim of this research project? • Has the author cited one or more references? • Has the author used the author/date system correctly? • Have all references been entered into the "Reference" section correctly (alphabetically by family name, full title of book or journal, correct page numbers or journal volume and page numbers)?

learning. It also reduced the time wasted by tutors on simple correction and editing, giving them time to provide constructive feedback and focus on the students' understanding, interpretation and execution of the journal instructions.

The first activity (Table 2) was given to the students on the Friday before the start of the experimental work on the following Monday. Completion of that activity ensured that the students had read through the laboratory manual, had completed some background research and understood the aim of the project. In addition, creation of a framework of headings for their paper helped the students to focus on the different components of a scientific paper and allowed data and ideas to be added as the experimental work proceeded.

The second activity (Table 3) focused on ways to present appropriately labelled and titled figures in the Results section, and how to compose accompanying text.

The final writing activity dealt with the Discussion section of the scientific paper (Table 4) and aimed especially to help students understand the different information found in Results and Discussion subsections of a paper. Both this activity and the previous one were completed on the fourth day of experimental work, when the students had their own gel and immunoblot results to work on and interpret.

Data collection and analysis

Evaluation of the writing activities relied on pre- and post activity surveys. Students were informed of the purpose of the writing activities and surveys in the first introductory lecture. Participation in the surveys was voluntary and anonymous. The post-writing survey was completed by students after they had written their final report.

The closed items of the surveys were designed to capture student perceptions of the writing activities, specifically the quality of training in scientific writing, confidence in their own overall writing ability, their ability to produce figure legends, confidence in knowing what information goes into results and discussion, and how to construct a logical flow of information within and between sections. Respondents were asked to circle one number on a Likert scale rating from 1 to 5. The data were analysed using the Minitab Statistical Software package and applying the Mann-Whitney Two Group test, which tests whether there is a difference between two population medians (McCleery, Watt, & Hart, 2007).

Open questions further assessed student opinions and concerns and sought comments on all aspects of the writing activities.

RESULTS

Students were surveyed for their opinions on a range of attributes associated with scientific writing both prior to, and following their participation in a laboratory class that incorporated writing activities. For every category surveyed using closed questions, there was a highly significant increase in confidence or an improved assessment by the students of their ability to write a

Table 3. Writing activity designed to train students in the correct presentation of experimental results as figures in a Results section

Results Section	Checklist
a: Incorporating Figures in Results *In the space below, download a scanned image of your SDS-PAGE result and matching blot. Give your figure a figure number and a title. Clearly label all lanes using numbers. Explain what each lane number represents in a figure legend. Indicate the size of the MW markers.* *NB: it will not be enough to include only the figures in your Results section. You will need explanatory words to accompany each Figure to complete the results: see part b of this activity*	**a** • Is the Figure title concise but informative? • Are all the lanes numbered? • Are there sufficient details in a legend or beneath the title? • Have the MW marker sizes been included?
b: Describing Results *Write a paragraph for your Results section highlighting important data from your gel and immunoblot results.* Remember that it is not enough to include only actual figures and tables in your Results section. You need to also provide some text to accompany any figure or table so that the reader can understand: 1. *what you were doing* 2. why you were doing it, and **3. what you found** Example: *Immunoblotting was performed* to identify GAPDH in fractions of rabbit skeletal muscle**. A single band of X Da was observed in each sample (Figure Y, lanes 1-4)** etc. etc.	b Does the Results paragraph answer • "what were you doing", • "why were you doing it" and • "what did you find"?

scientific report (Figure 1). The median value on the Likert rating scale for the student assessment of the quality of their prior training in scientific writing was 3 ("average") whereas the quality of the recently completed writing exercises had a median value of 4 ("good") (Figure 1B). The median value for responses to questions on the students' confidence in their ability to write a figure legend (Figure 1D) increased from a value of 2 at the commencement of the course up to 4 after completion of the writing exercises, indicating increased confidence in their ability. Median values for all the other attributes surveyed (Figures 1A, C, E, F) increased from 3 to 4, also reflecting an increase in student confidence. The significance of these changes was analysed using the Mann-Whitney two group test for non-parametric statistics and in all cases was highly significant ($P<0.0001$).

Student responses to open questions at the start of the Biomolecular Sciences Laboratory course revealed that 97% of the students read scientific papers and were confident in their ability to find scientific journal articles using databases such as PubMed. About 25% of the class did not realise that the format required for their paper was typical of formats utilised by scientific journals. The students provided a range of responses when asked to identify what aspects of scientific writing seemed most daunting. Some comments highlighted the challenge of getting started, others were particularly concerned with spelling, grammar and sentence structure (~23% were English second language students) and there was general concern over particular subsections, both how to write them and what information they should contain.

An open question about the students' expectations of the scientific writing activities indicated that the majority hoped the exercises would help them learn about correct scientific writing, know what information should be found in each section and become proficient at scientific writing. Four of the 39 students who responded to this question specifically expected that the tasks would help them in their future careers, while four others predicted that the tasks would be difficult and one thought they might be tedious. At the end of the course 100% of respondents (32/32) agreed that they had found the activities useful, with four of these singling out their value and relevance to future careers. Students also agreed that there had been other positive learning outcomes (Table 5).

DISCUSSION

Students entering the third year undergraduate course, Biomolecular Sciences Laboratory, rated their prior training in scientific writing as below average but rated the integrated writing activities very highly (Figure 1B). Several students commented that such training should have occurred earlier in their degree program:

The writing tasks have been very beneficial. If for no other reason I'm glad to have taken this course as I've learnt how to write well. I wish something like this had been made available earlier.

I think that something like this should be introduced earlier (e.g. second year) rather than 6 months before most people finish (half way through third year). Because this is such a valuable skill and I think at the moment it isn't valued high enough in the learning/teaching environment.

These views concur with those expressed by the editors of the Journal of Young Investigators (Ali, et al.,

Table 4. Writing activity designed to train students in distinguishing factual information that should be in the Results section compared to interpretive and analytical commentary that should be included in the Discussion

The Discussion versus the Results	Checklist
Discussing a Result *Write a paragraph for your <u>Discussion</u> section by interpreting <u>what your immunoblot results mean</u>.*	• Have attempts been made in the Discussion to explain what the results mean?
Each significant result that you report in your Results section needs to be 'discussed' in your Discussion section. This writing task is designed to help you know where to put your information.	• Does the Discussion contain irrelevant data from the Results or Methods section?
You have already reported your immunoblot results (that is, what you found) in the form of a figure (Table 3, a) and accompanying text (Table 3, b above). *This goes in your Results section!* You will then discuss the meaning and implication of these results. *This goes in your Discussion!*	• Are the explanations supported by relevant references (correctly cited)?
As a guide you may want to discuss: • whether the results were expected (i.e. did it work!) and if not, why not • were there limitations associated with the work • how the findings of your immunoblot relate to your other data and to other published data	• Have the immunoblot findings been correlated with e.g. the enzyme activity data? • Has the related work of others been cited?

2007) who are strong advocates of the early introduction of science writing and communication into undergraduate research programs.

Features of successful writing training identified by Jerde and Taper (2004) were direct integration of scientific writing into specialised courses and instructive interaction between staff and students. The results from our program of integrated writing activities and expert guidance and feedback to the students support the use of their model for training in scientific writing. Success in writing evidently relies on more than the provision of clearly written instructions in the form of a journal's guidelines to authors, further explanations, hints and examples (as had been provided in this course prior to 2008 and is a consistent feature of many reports that describe teaching of writing skills (Whelan & Zare, 2003). The addition of simple, compulsory writing activities had several obvious benefits. The students started on their report while expert guidance was available. The need to show their work to tutors throughout the week of predominantly experimental work meant that the students wrote small amounts every day. The practice of brief daily writing periods, instead of the traditional approach of waiting for a block of time to devote solely to writing, is one that was advocated originally by Boice (1989) and recently by Martin (2009) as an effective way to increase research paper productivity. As with most learned skills, practice is the key to success. Collaborative learning also occurred when laboratory partners were responsible for the initial reading and checking of their partner's work. The provision of the checklist, which highlighted standard journal requirements, led to greater rigour in following instructions. Finally, the skilled guidance by the tutors enabled the students to see how sections of their work could be improved and gave the students sufficient confidence to proceed independently with the remainder of their report. From the students' point of view, a great benefit was that all the work done on the writing activities could be incorporated directly into their final scientific paper.

Of the sixty six students who participated in the preliminary survey, all but two had read scientific journal articles and considered themselves competent at accessing and using databases, such as PubMed, to find useful journal articles. However, it is clear from their initial lack of confidence in their ability to write a scientific report (Figure 1A) and perform relatively simple tasks, such as writing a figure legend (Figure 1D), that their reading of scientific journal articles had been a passive and uncritical activity. They remained unaware of the relatively standard style required for publishing scientific articles and a quarter of the class had not recognised that research is regularly published in the format that we required them to follow. Until undertaking the active learning fostered by our writing activities, students may have regularly used journal articles as a source of information but few had realized that the articles were a model on which they could base their own writing. Their confidence in their ability to write the Introduction (Figure 1C) and figure legends (Figure 1D) improved markedly once they had completed the exercises. Their understanding of the type of information that should be included in Results versus Discussion, and their ability to write a logical, flowing report also improved (Figures 1E, F) although to a lesser extent than seen with the confidence in writing figure legends and an introduction. This

Table 5. Student responses to provided statements that listed possible learning outcomes related to completion of writing activities integrated into a third year undergraduate laboratory course. Surveys undertaken after course completion

Statement	% Agreeing
Understood better what each section of a scientific paper should contain	100#
Understood that the way in which the lab report was written is how research is presented for publishing in a 'real' laboratory	100@
Learnt to link individual experimental results, to create a flowing written report	100@
The writing activities saved me time when it came to completing the final report	100@
Learnt to write in a 'scientific style' rather than using everyday English	91@
Understood better how each experiment relates to the others	82@
Learnt how to label figures and/or tables correctly	81#
Understood better the purpose of the experiments	78#
Learnt how to cite references and how to list them at the end of the report	74#
Learnt how to search for relevant information on scientific websites	44#
Began to read scientific papers more critically	44#

 # 32 respondents (total enrolment 70), combined data from 2008/2009; @ 11 respondents (total enrolment 32), statements surveyed only in 2009

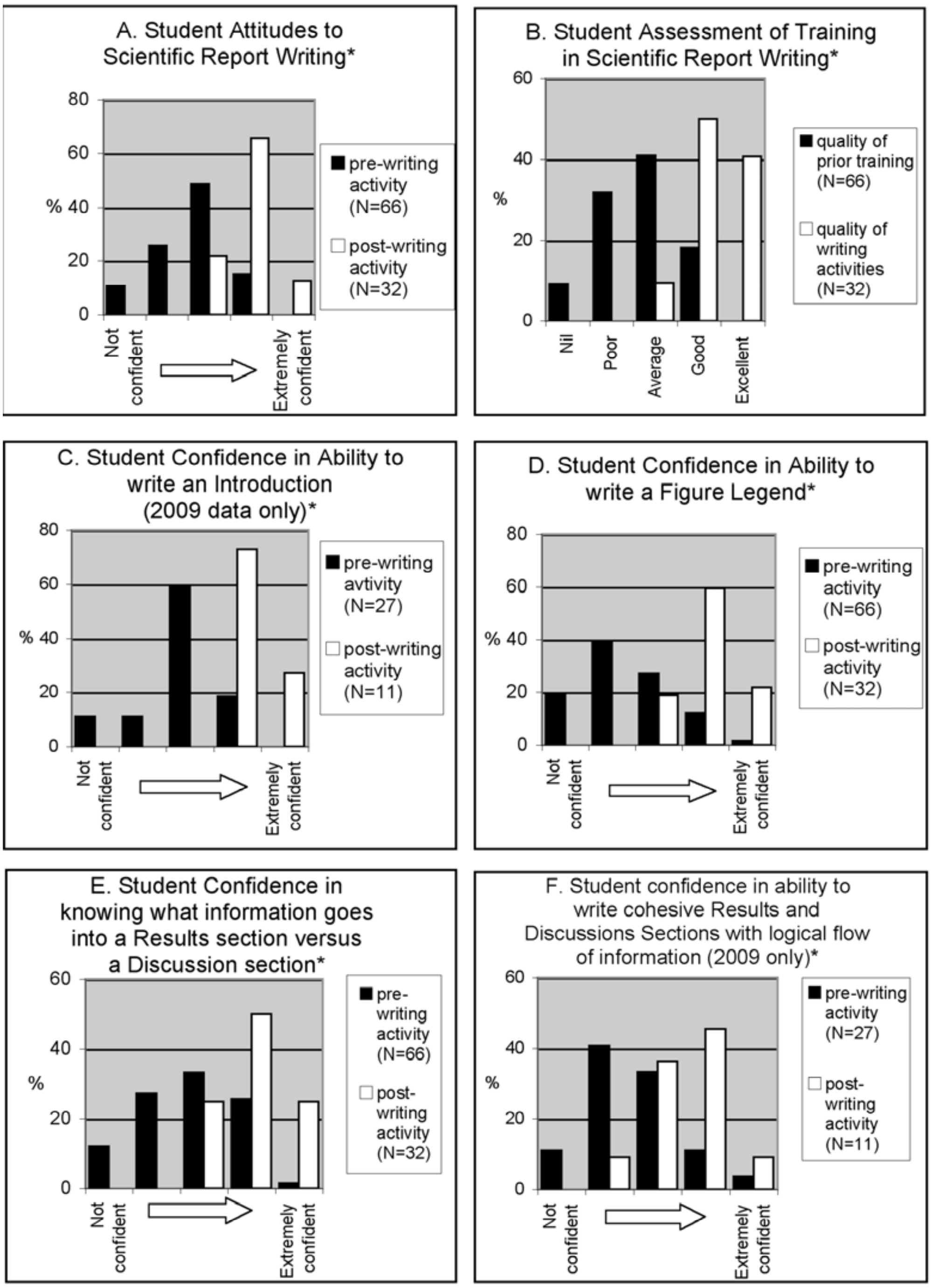

Figure 1. Student opinions on their scientific writing training and ability (A, B) and their confidence at performing various scientific writing tasks (C-F)

The Likert rating scales were: Figures 1 A, C-F: student confidence levels from "Not confident" (= 1) through to "Extremely confident" (= 5); Figure 1B, rating scale of 1 = Nil, 2 = Poor, 3 = Average, 4 = Good, 5 = Excellent).
**Significant differences between the pre- and post-writing activity surveys (by Mann-Whitney test (two group); P<0.0001)*

difference probably reflects the relatively simple rules that help to create a useful figure (e.g. precise and extensive labelling, keys, informative title) compared to the more challenging analytical and critical thinking that is involved with assimilating the meaning of experimental data and the inter-relatedness of different experiments.

The initial lack of confidence in ability to write a figure legend is somewhat surprising, as most students have previously constructed bar charts and simple figures for other courses in mathematics, statistics and chemistry, and the same rules for labelling and clear titles apply. However, the tendency for students to compartmentalise different disciplines, the lack of explicit previous training for reporting experimental bioscience and the uncritical reading of bioscience journal articles may explain this initial response. The improvement in confidence after the students were made familiar with what is involved in creating a figure and received some expert feedback on their efforts, shows that relatively minor changes to teaching strategies can have major student learning outcomes. We believe that use of the students' own data was a key to engaging the students in the cycle of writing, feedback, editing and application of learned principles to the rest of their report.

Many students listed the time-saving aspect of writing the report concurrently with the experimental work as an advantage. This pragmatic attitude to the work probably contributed to the very positive responses to the compulsory completion of writing activities during an already busy week of experimental work. Few students spontaneously nominated less obvious advantages to completing the exercises, such as whether the activities helped with understanding the work. However, when specifically questioned on other possible benefits of completing the writing activities there was agreement that the activities had promoted better understanding of the purpose of the experiments, how each experiment related to the others, and how it was possible to link outcomes of different experiments to create a flowing written report (Table 5).

The change in attitude and confidence levels is an additional advantage of this type of applied training program. The survey results (Figure 1) show remarkable improvements in student attitudes to report writing and confidence in their ability to complete sections of a scientific paper. These changes, brought about by the activities, were cited by some students as the best thing about the writing tasks:

Gained more confidence in writing scientific reports

They were very helpful and relevant. I definitely feel they have helped me to get started on my report as it didn't seem so overwhelming as I had already started (by having done the writing exercises) and the feedback allowed me to track my progress and implement corrections for future figures etc.

The writing tasks have been very helpful in preparing to write the final report. Usually I would leave everything until the end and then freak out and not know where to start so the writing tasks have helped prevent his happening. Being able to receive continuous feedback from (the tutors) was also very helpful and apart from writing the discussion section in a continuous way I am feeling much better prepared to write the final report than I would have been without them.

They also acknowledged that what they had experienced in this course may be relevant in the future:

This course was fantastic and has left me with key knowledge I hope will help me get a job.

It is awesome to get a hands-on class that covers techniques that are important to know. Also experience in journal writing is very helpful.

On the whole the lab was stressful and hard, and I enjoyed every minute of it. It was a challenge and a good representation of actual lab work.

Really helped put things in perspective, would enjoy doing these activities outside the course.

Thus some of the success of the writing activities lies both with their relevance to the immediate challenge of producing a well constructed final paper, and the relevance to a future career, in which scientific communication ability is a core skill for professional scientists.

Training in scientific writing can occur in courses separate from an experimental laboratory course but advantages of integrated writing exercises are that the students themselves have generated the data about which they are writing (giving them ownership and true insight into how the data was obtained). In addition, the writing output contributes directly to their final paper instead of being merely an extra assignment appended to a course. For example, one student said:

They were related to the work we were carrying out in the lab. So you were learning with experiments that were familiar.

Another factor that contributed to the success of the activities was the style and quality of the feedback given to the students. For maximum effectiveness the tutors need to be patient, approachable and knowledgeable – all positive features of our team that were remarked on by our students:

It was awesome having demonstrators and a coordinator that were all so friendly and approachable; it made the course more enjoyable

However, the tutors did not provide feedback on the entire paper. Instead, they provided encouragement, expertise and positive feedback which gave the students sufficient knowledge and confidence to proceed independently and apply learned principles.

Did these writing activities satisfy the expectations of the students? Prior to starting the course, the majority of students hoped that the writing exercises would help them become proficient at scientific writing and a small number of students expected them to be difficult and possibly tedious. The final survey results showed that 100% of respondents believed that the writing activities had been useful, and identified many positive learning outcomes including a better conceptual understanding of the whole project. Although the number of respondents for the post-course survey was small, the changes were statistically significant. It is believed that the responses reflect the majority view as a general survey of all aspects of the course, issued on the final day of laboratory work, was returned by 75% of the course participants. All of these responses commented favourably on various aspects of the course, including the writing exercises. Thus the evidence indicates that the writing activities achieved all that the students expected, and had additional learning benefits not predicted by the students.

CONCLUSION

Overall the inclusion of writing activities into an experimental laboratory course was an effective interactive teaching method, similar in its key features to the model described by (Costa & Rangachari, 2009). The writing activities promoted conceptual understanding through active engagement in "hands-on" (production of experimental data) and "heads-on" (analysis and interpretation of data) activities. Use of self-generated data was a significant feature that stimulated student interest and engagement. The immediate feedback that was provided through discussion with their fellow students and tutors also enhanced student learning.

The significant changes revealed in the statistical analysis of our surveys strongly support the introduction of simple writing activities, integrated into a laboratory class, as an effective strategy to enhance communication skills of bioscience students.

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