Development of Scientific Writing Skills Through Activities Embedded into Biochemistry and Molecular Biology Laboratory Courses

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Abstract

Scientific writing skills are important for a career in science and need to be developed. Rather than design courses solely focused on writing, we embedded writing activities into two bioscience laboratory courses at third year undergraduate level, where students wrote about their own data. Students completed writing exercises during breaks in experimental procedures and received feedback during the session. These activities focused on data presentation, data analysis and writing results and discussion paragraphs. These exercises provided a model to assist students in writing the remainder of the report. We probed student opinions regarding scientific writing and the exercises by anonymous pre- and post-course surveys using both closed and open questions. Confidence towards scientific writing and performing simple writing tasks significantly improved after experiencing the writing activities in the first course. Students related that undertaking writing activities in more than one class helped to further improve their writing skills. Independent assessors, with no knowledge of when the reports were written, evaluated reports that originated from the same course held in years before and after writing activities were incorporated. There was a significant improvement in scientific writing quality that correlated with the increase in students' self-efficacy towards performing various writing tasks.

Introduction

Science is not just about performing experiments; communicating the results is also essential. Imagine if major discoveries went unrecognised because scientists could not convey their findings in a coherent manner. What if the accidental discovery that mould possessed antibacterial activity had never been published by Alexander Fleming in 1929 (Fleming, 1929)? Then Florey and Chain would not have had the necessary information to identify penicillin as a powerful antibiotic, which saved many lives during World War II (Chain, Florey, Gardner, Heatley, Jennings, Orr-Ewing & Sanders, 1940) and is used to this day.

The need to communicate has been emphasised by other well known scientists. Sir Francis Darwin, the son of Charles Darwin, was quoted as stating "*In science the credit goes to the man who convinces the world, not to the man to whom the idea first occurs*" (Plain Language, 2004) and Albert Einstein also recognised the need to write for a broad readership "*Most of the fundamental ideas of science are essentially simple, and may, as a rule, be expressed in a language comprehensible to everyone. Everything should be as simple as it can be, yet no* *simpler*" (Plain Language, 2004). However, the focus of much of the science curriculum is on learning facts and concepts and developing problem solving skills. Far less time is spent developing scientific communication skills.

Science students are also often focused on developing their knowledge and technical skills, but in reality it is their written skills that will ultimately strongly influence their ability to publish journal articles, prepare reports and to obtain grant funding. Thus, the success of scientists in the greater scientific community hinges on their ability to communicate effectively. Yore, Hand and Florence (2004) surveyed and interviewed professional scientists who agreed that written communication is highly valued within the scientific community. Such communication also generates insights and clarifies ambiguities. In addition, it is recognised that "*Scientists who communicate well are successful in gaining recognition and support from members of their own communities, the research funding agencies, and the wider society*" (Yore, Hand & Florence, 2004).

It has been suggested that there has been a decline in writing skills amongst students in recent years, with the advent of technology proposed as one possible reason (Stormshak, 2004). Contributing to this decline may be a stated dislike of writing amongst biology students; however, the majority of those surveyed nonetheless recognised the importance of scientific writing for their future careers (Crepeau, Hardy & Benassi, 2003; Malacinski and Waterman, 2012). Therefore students appreciate the need to improve their writing, but need motivation and practical training on how to do so. Merely providing instructions and guidelines is not sufficient; rather, use of active learning techniques shifts the focus to students "doing" things and ensures that students take charge of their own learning (Biggs, 2003). As Tyler stated "*Learning takes place through the active behaviour of the student; it is what he does that he learns, not what the teacher does*" (Tyler, 1949). This active learning philosophy must also be applied to scientific writing training if it is to be effective.

Scientific writing training also has other positive outcomes and purposes. Students who experience such instruction as part of their undergraduate laboratory course have significantly improved critical thinking skills (Quitadamo & Kurtz, 2007). More recently, "Writing-to-learn" practices, documented in the literature and collated into a unified resource, have been advocated as teaching strategies that can advance student learning and engagement with science, technology, engineering and mathematics (STEM) disciplines (Reynolds, Thaiss, Katkin & Thompson, 2012). Thus, to incorporate writing training into science curricula both provides an essential part of that scientific training, and also brings other advantages.

Various approaches to incorporating scientific writing have been taken by different universities. Stand-alone writing courses have been designed and advocated by some, while others have incorporated writing training into standard courses (Jerde & Taper, 2004; Robinson, Stoller, Horn & Grabe, 2009; Malacinski & Winterman, 2012). The challenge is to make scientific writing training meaningful for the students so that they become actively engaged. Our approach, which is described in this paper, was to embed specific writing training into undergraduate laboratory courses. Students were required to write about their own data, as they progressed through the course, and they received feedback on their writing.

Rationale and Goals of Our Project

Our goals were to encourage students to write by improving their confidence and attitude towards writing with the ultimate aim to improve their overall scientific writing ability. Our approach was to embed scientific writing exercises into two different pre-existing bioscience laboratory courses. Using their own data, students completed short writing tasks that drew on the theoretical background and outcomes of their experimental work. They wrote on the data that they generated during the practical course. Students received feedback so that the responses to the tasks could be improved (if required) until the teacher was satisfied.

Our approach was built on findings that students obtain a greater benefit when they are writing about what they themselves have actually done (Jerde & Taper, 2004) – they "own" the data. Moreover it has been stated that when writing tasks are integral to the laboratory activity students are more likely to find such tasks meaningful and engaging (Moskovitz & Kellogg, 2011). Our writing activities were designed to be directly relevant to the data that students were generating and analysing in the laboratory class. Students can complete the writing activities while their experiments are running and therefore this is a cost effective and time efficient strategy. It also reflects what is recommended for a professional researcher, where writing regularly from the start of a project is promoted as a means to develop, clarify and test ideas during the experimental phase (Martin, 2009). From a student perspective, they commence the writing while still performing experimental work, allowing them to receive timely feedback on their writing. Since the feedback is given on their own writing, students can track their own improvement. Engaging with the activity is therefore rewarded.

We also asked students to self-report their own perceived confidence with respect to various scientific writing skills, in effect their writing self-efficacy levels. Self-efficacy has been defined as a person's belief in their own ability to perform certain specific functions (Shoemaker, 2010). It is regarded as a better indicator of performance than self-confidence, which is more broadly defined (Shoemaker, 2010; Briggs, 2014). In addition, others have shown that student beliefs about writing, specifically their confidence in their own ability to perform specific tasks concerned with writing, correlate with performance (Sanders-Reio, Alexander, Geio & Newman, 2014). Therefore we were interested to determine if the students' self-efficacy for scientific writing influenced their performance in preparing their final written report.

We have incorporated our writing activity strategy into two different third year undergraduate bioscience laboratory classes run in different formats (intensive mode versus weekly sessions). In the initial course run in intensive mode students spent one full week in the laboratory and experienced specific writing activities during breaks in experimental work throughout each day. Students regarded the writing activities as beneficial and their confidence towards scientific writing increased by the end of the course (Lee, Woods & Tonissen, 2011). In this current paper we describe the incorporation of writing activities into a more traditionally run laboratory class (with 4-hour laboratory sessions over several weeks). Since most of the students had already taken the initial course we were able to probe the opinions of students who had previously undergone this type of training and determine if they retained any confidence arising from their first experience. In this report we also assess if the writing activities contributed to an improvement in quality of student written reports.

Context

Griffith University is a comprehensive teaching and research university with campuses in Brisbane, Logan and the Gold Coast, with a student population of 43,000, from more than 150 countries. Innovative teaching practices are encouraged by the university. Within the Sciences group, the School of Natural Sciences offers degrees in science, biomedical science, biomolecular science, forensic science, and aviation. These are typically three year programs with a specialised optional Honours research year in the fourth year for suitably qualified students. The biosciences disciplines use stand-alone laboratory courses run in the second and third year of the programs for practical training.

The Biomolecular Sciences Laboratory (3035BBS) was a third year undergraduate laboratory course focused on biochemistry concepts. Students enrolling in this laboratory course were required to have passed a second year level competency based techniques course (Di Trapani & Clarke, 2012), but had not had prior specific training in scientific writing. Previous writing experience had been limited to essays and assignments in other courses, including a first year level social studies of science course. The laboratory course was offered over a one-week intensive-mode format in the students' winter break, for 8 hours every day. Their project involved the isolation, purification and characterisation of an enzyme from rabbit skeletal muscle. After the practical work students were expected to submit a short scientific paper that described their laboratory work and was written in a recognised journal format.

The Biotechnology Laboratory course (3009BBS) was a third year undergraduate laboratory course that was focused on molecular biology and recombinant protein expression. Students first mutated a sequence using polymerase chain reaction (PCR), cloned the insert and prepared plasmid DNA. Recombinant proteins were then expressed in *E. coli*, run on SDS-polyacrylamide gels and activity assays performed. The laboratory ran over five weeks, with two weekly sessions each four hours long. The students were quizzed on their experimental knowledge and were also expected to write a scientific report on their findings after the practical work had been completed.

Table 1: Courses in which writing activities were embedded.

	3035BBS	**3009BBS**
Course Name	Biomolecular Sciences Laboratory	Biotechnology Laboratory
# students (2008 and 2009)	66	31
Level	Third year undergraduate	Third year undergraduate
Content	Biochemistry	Molecular Biology and Biochemistry
Style	Project	Project
Mode	Intensive mode during winter break (One week)	Two x four-hour sessions each week for five weeks
Assessment	Report in the form of a scientific paper (100%)	Laboratory report (60%) and two quizzes (20% each)

The Writing Activities

Writing activities were embedded into two third level courses, as described in Table 1. Activities required students to write on their own data being generated in the laboratory class. Students completed the activities during breaks in their experimental work, for example while reactions were incubating or gels were being run. Each writing activity had a checklist to be marked off initially by each laboratory partner, before a staff member provided feedback. The checklist enabled students to focus on the key objectives for each activity and the peer evaluation provided benefits to the student doing the teaching (correcting) since as Biggs (2003) states "teaching the subject deepens students' cognitive understanding". The writing activities for 3035BBS have been previously described (Lee et al., 2011), while the first three writing activities for 3009BBS are shown in Tables 2, 3 and 4. These activities were designed to provide practice in preparing figures and figure legends, writing paragraphs to support figures and other data, and writing about their data analysis and its significance. The final two writing activities gave further opportunities for figure presentation, data analysis and decisions regarding which information should be included in the results and discussion sections. Therefore some simple tasks, such as labelling figures, were framed within practice tasks to develop higher order writing skills such as data analysis and interpretation.

The peer review also reduced the need for staff to correct simple errors and allowed more time for constructive feedback and focus on the students' understanding, data interpretation and execution of the report writing instructions. Students repeated the task until it was deemed satisfactory. The completed activities could then be incorporated directly into their final scientific reports. Feedback on the entire report was not provided. Instead, students were given feedback on typical subsections and were then expected to apply the learned principles to similar sections of their paper.

Table 2: The first of five writing activities was designed to help students label figures and write a figure legend.

Writing Activity 1 – Labelling Figures	**Checklist**
Using a hand drawn gel image representing the results you observed in today's session, clearly label all lanes using numbers that are fully explained in a figure legend. Give your figure a title and indicate the size of prominent Molecular weight (MW) markers.	• Is the title concise and relevant? • Are all the lanes numbered? • Does the figure legend provide adequate information? • Have MW marker sizes been included?

Table 3: The second activity was designed to help students write the opening paragraph of the results section to provide some context for the experiments being undertaken.

Writing Activity 2 – Write the first paragraph of your results chapter	**Checklist**
First think of what you want information you think should be included in this paragraph. This will include information relating to your Polymerase Chain Reaction (PCR) reactions. Remember, it is not enough to include *only* figures and/or tables in your results section. That is, you need some *words* accompanying your figures and/or tables. The reader needs to know: **1.** What you were doing **2.** Why you were doing it, and **3.** What you found Think about what technique you used and why you set up those reactions - what was their purpose. Highlight important data from your newly created 'Figure' and refer to this in your results paragraph. List any key words or phrases and put together some rough sentences. Then smooth out from there.	Does the paragraph answer: • What experiment was being done? • Why the experiment was being done? • What the experiment found?

Table 4: Writing Activity 3 was designed to help students determine what should go into their discussion chapter.

Writing Activity 3 – What to put into your discussion section.	**Checklist**
Write a paragraph for your Discussion chapter by interpreting what your PCR results mean. Each significant result that you report in your Results section needs to be 'discussed' in your Discussion section. Too often people get confused with whether information should go in the Results or Discussion. This writing task is designed to help you understand where to put your information. You have already reported your results in the form of a figure and accompanying text. *This goes in your Results section!* You will now discuss the meaning and implication of these results. *This goes in your Discussion!* Firstly, write down some key words that will help you to form your discussion. As a guide you may want to discuss: **1.** Whether the results were expected (ie did it work!) and if not, why not **2.** Were there any limitations associated with the experiment **3.** How the findings of your PCR relate to, and affect, your other data (obviously this could only be discussed once you have completed all experiments)	• Have attempts been made in the Discussion to explain what the results mean? • Does the Discussion contain irrelevant data from the Results or Methods section?

Methodology

Ethics approval for the research phases of this project was given by the Griffith University Human Research Ethics Committee. Evaluation of student self-rated confidence towards various scientific writing attributes (writing self-efficacy) was performed by voluntary and anonymous surveys conducted before and after each laboratory course. Students were given information sheets that described the purpose of the writing activities and surveys in the first introductory lecture and then gave consent for their answers to be used for research purposes. Surveys were performed in both 2008 and 2009.

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, knowledge of 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 shows whether there is a difference between two population medians (McCleery, Watt & Hart, 2007). Open-ended questions further assessed student opinions and concerns and sought comments on various aspects of the writing activities.

To evaluate the writing activities from the teaching staff perspective and to monitor if improvements had been made to the quality of the written outputs, two independent assessors were appointed to analyse reports from years before writing activities (55 reports from 1998-2005) and after writing activities (30 reports from 2008-2009). Both assessors were asked to re-grade all reports based on the same criteria and were asked to fill in survey forms where they rated the quality of figures, figure legends, interpretative ability, understanding of laboratory aims and significance using a 4-point Likert scale. These assessors had not previously marked any of these reports and were given reports that did not contain any identifying information such as student name, the year of report or the original mark awarded to the report. The assessors marked each report independently of the other assessor. Example reports were used as practice to ensure both assessors were interpreting and applying the criteria consistently. Consistency between assessors was also verified by selecting a sub-group of re-graded reports and reviewing the marks awarded for each section. Holistically the final overall marks for each report (since each report was marked by both examiners independently) was also compared to ensure that the marks were being consistently awarded.

Results and Discussion

Analysis of student opinions towards writing and the writing activities
Writing activities were embedded into two third year level Bioscience Laboratory classes (Table 1). Students were surveyed before and after each course for their self-efficacy levels towards scientific writing and for how they regarded the writing activities (similar survey instruments were utilised for both courses to obtain comparative data). A previous report based solely on the 3035BBS course showed that students thought that writing activities improved their confidence towards writing (Lee et al., 2011). Many students who took the 3009BBS course had just finished taking the 3035BBS course (held over the winter break). This enabled us to determine how much of the initial training that they retained and whether performing the same task, but using different underlying experimental data and methodology, was of benefit to the students. The results are illustrated in Figure 1.

Overall the results show that students entered the 3009BBS course with a higher self-reported confidence level towards scientific writing than when they started the previous course (3035BBS). Only 6 students (out of 31) took the 3009BBS class without previously taking the 3035BBS class. The results presented in Figure 1, Panel A show students entering the 3009BBS course rated previous writing training as higher than the rating awarded by students entering the earlier course, 3035BBS. This suggests that students entering the 3009BBS course regarded the training they received in 3035BBS quite highly and relevant to their broader scientific writing ability and not just specific for 3035BBS.

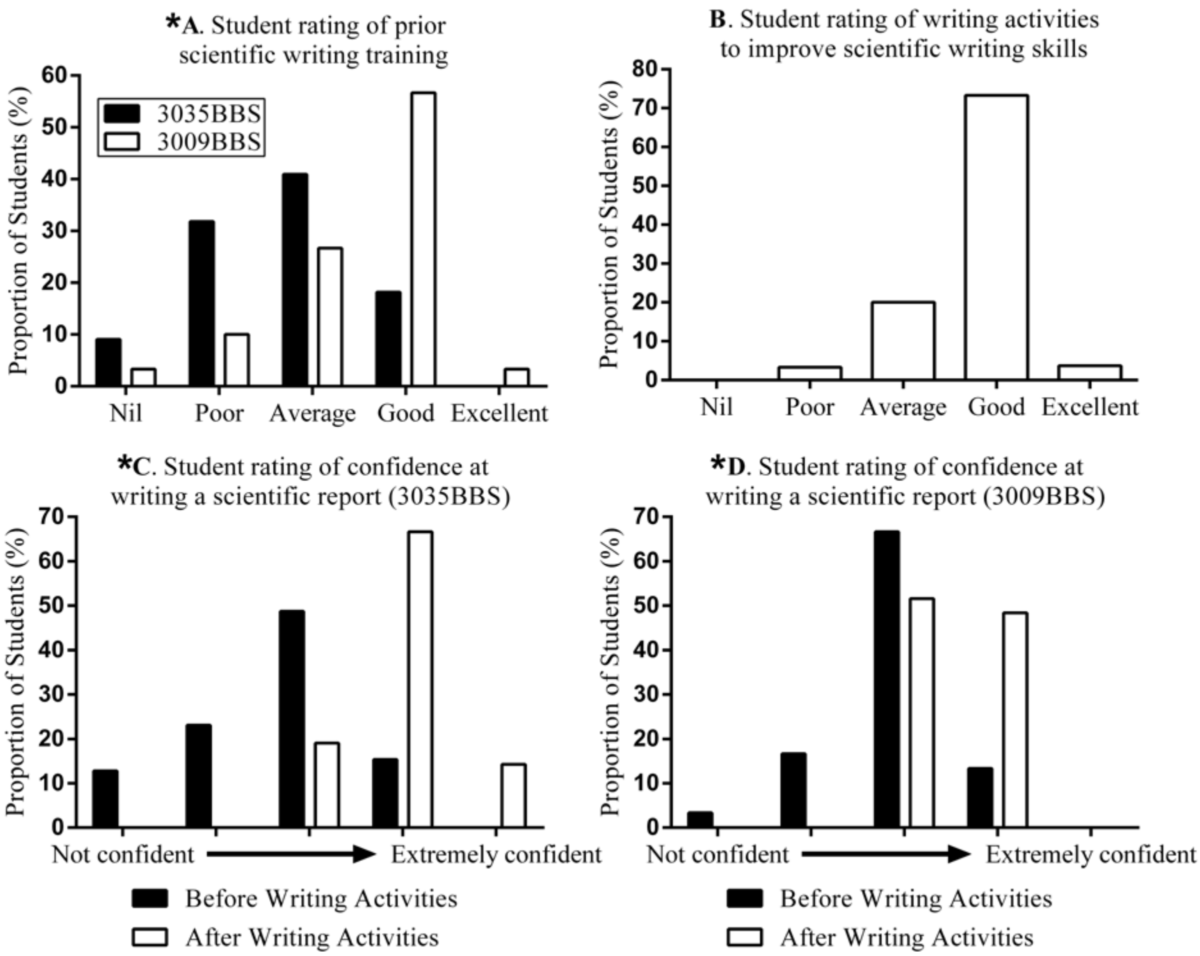

Figure 1: Student opinions on their scientific writing training and ability (A, B) and their confidence at writing scientific papers (C, D).

Panel A contains a comparison between the student rating of prior training for students entering the 3035BBS course compared to the 3009BBS course. Panel B contains the student rating of the activities performed in 3009BBS course. Panel C contains the student rating of their confidence at writing a scientific report for the 3035BBS course and Panel D contains student rating of their confidence at writing a scientific report for the 3009BBS course. The Likert rating scales were: Panels A and B: rating scale of 1 = Nil, 2 = Poor, 3 = Average, 4 = Good, 5 = Excellent. Panels C and D: student confidence levels from "Not confident" (= 1) through to "Extremely confident" (= 5); Panels A-D contain combined 2008 and 2009 data.
*Significant differences between the pre- and post-writing activity surveys (by Mann-Whitney test (two group); $P<0.001$) were obtained for panels A, C and D.

Panel B shows that students in the 3009BBS course also highly rated the writing activities. This indicates that having the writing activities twice in a short period (within two months) was still considered worthwhile and helpful by the students. Panels C and D show the students' confidence levels towards scientific writing before and after the 3035BBS and 3009BBS courses respectively. In both courses the students still related a significant improvement in their confidence towards scientific writing.

These results show that undertaking the same teaching strategy more than once provides a benefit to the students and that they regard this type of active learning approach as helpful to

them. For example, typical comments in the open-ended questions for the 3009BBS course were: *"The more you do, the more confident you are"* and *"Writing task were easier after doing course over winter (3035BBS). Really appreciate opportunity to get feedback on writing tasks"*. Similarly, students also commented on the enjoyment of science more now that they were more confident in their writing and understanding: For example
"I am really learning a lot of stuff. I will keep on asking where I don't understand and to be honest I am starting to enjoy science"

For the post-course survey students were provided with a list of possible learning outcomes and were asked to indicate which of these outcomes they felt were appropriate for what they gained from the writing activities. These responses are shown in Table 5.

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. % in agreement is shown. 31 respondents, combined data from 2008/2009.

Statement	% agreeing
Understood better the purpose of the experiments	91
Learnt how to label figures and/or tables correctly	91
Understood better what each section of a scientific paper should contain	84
Learnt to link individual experimental results, to create a flowing written report	77
The writing activities saved me time when it came to completing the final report	77
Understood better how each experiment relates to the others	69
Learnt to write in a 'scientific style' rather than using everyday English	62
Began to read scientific papers more critically	52
Learnt how to cite references correctly and how to list them at the end of the report	45
Learnt how to search for relevant information on scientific websites	29

The responses by the students as shown in Table 5 were reflected in the open answer sections of the survey. For examples many students commented on how writing activities helped them improve their writing with generalised comments such as: "*Improve my scientific paper writing ability"* and more specific comments such as "*Gaining confidence that I'm putting the correct info in the correct section"*.

Students also revealed that they appreciated the time management and organisation aspects with comments such as: "*The writing activities help to get feedback and get the report started early"* and "*Good feedback and being forced to consider certain results before the final write up"*. Interestingly 91% of students responded that they understood better the purpose of the experiments with the comments supporting this assertion: *"Allowed me to think critically"* and *"Allows me to understand more clearly why we did certain things in the lab"*.

The writing activities incorporated into the 3009BBS course were not designed to train students in referencing or for searching databases and it is therefore noteworthy that students were discriminatory in the way that they filled in the surveys and only acknowledged the relevant benefits of the writing activities (such as better understanding of experiments, figure labelling, structure of report and linking experiments together) (Table 5). These were all attributes that we had focused on in the activities.

The immediacy and depth of the feedback is likely to be a contributor to the enhanced student scientific writing self-efficacy. Feedback loops are an important part of any learning process, where the type of feedback must be appropriate to have an impact on learning and to create a sense of achievement (Hattie & Timberley, 2007). Interestingly, these learning feedback loops mimic game theory where players can learn from their actions and improve performance and are thus rewarded for their effort with a sense of accomplishment. The adaption of game theory to education is fast becoming a popular theme in educational research (Snow & Seegmiller, 2011). Students are able to assess for themselves how they are performing, and the practice enables them to adjust and improve to meet the expected standards. They then receive the recognition and satisfaction that comes with successful completion of a task, or in our case the writing activity. Continued feedback loops reinforce the concepts, leading to enhanced confidence in their abilities to undertake the writing task.

Student and demonstrator feedback also contributed to improvements in our writing activity strategy. We learnt from the first year of using writing activities that it was important to have strategies in place to manage the time constraints of the writing activities since all the students wanted attention at the same time. We therefore were more insistent in subsequent years that the student's first draft must be checked by their student partner before a demonstrator would read it. To ensure that feedback was received in a timely manner we also trained more demonstrators to provide appropriate feedback. A further strategy that enhanced provision of timely feedback was to appoint staff to attend the course only at designated times in breaks from experimental work to read over the activities.

The embedded writing activities approach is also adaptable to laboratory classes run in different modes. We used it successfully in an intensive mode course (Lee et al., 2011) and also in a typical semester based course, as reported in this paper. It is also adaptable to other disciplines since the writing activities are focussed on the specific experimental concepts being taught in the laboratory course. Each of the laboratory courses used specific writing activities that were related to the actual experimental techniques and the data obtained. The required learning outcomes were similar with respect to data analysis and presentation and in each case the students responded positively that it gave them confidence with their writing.

Analyses of the quality of student reports

As shown above there was a significant improvement in student confidence in their writing ability. To determine if there was an improvement in writing quality to match this enhanced confidence an independent analysis of the written reports was undertaken. This was achieved by appointing two assessors who were not part of the project team but who had demonstrating experience in this laboratory class. We had a collection of reports from the 3009BBS course from class years before the writing activities began (55 reports from 1998-2005) and we had copies of reports submitted in 2008 and 2009 (30 in total). The assessors were asked to fill in a questionnaire for each report with respect to either the presence or absence of particular attributes and also to make judgment as to the quality of each section. Therefore each report was re-marked twice, once by each assessor. The assessors knew neither the year of report completion nor the grade awarded previously. Both assessors graded every report independently of the other assessor. Each report was marked against the same criteria and checks were made to ensure consistent application of the criteria, as described in the methodology section. Figure 2 shows the difference in scores awarded by each assessor to the pre-writing activity reports and post-writing activity reports and in comparison to the original scores awarded to the reports.

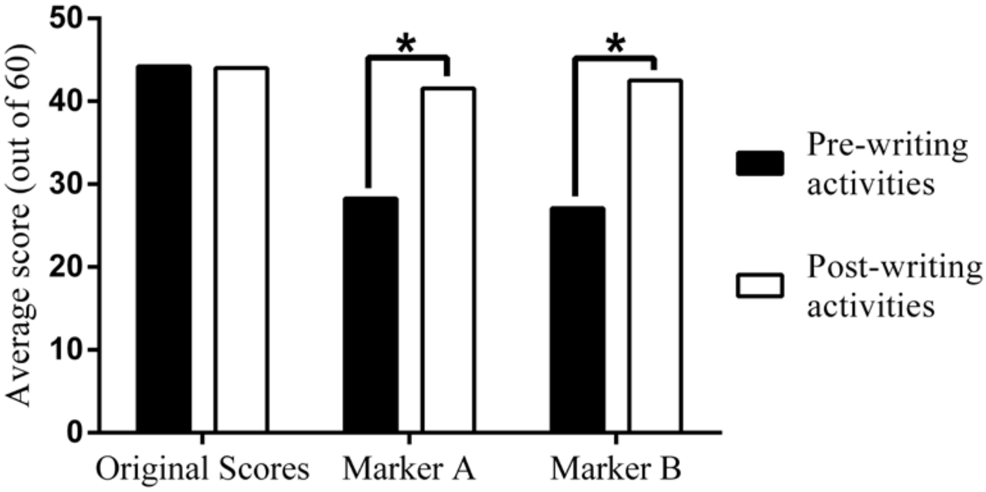

Figure 2. Marks awarded to student reports. Reports were marked out of 60 and were either from years when writing activities were not included in the course ("Pre-writing activities") or from years when writing activities were included ("Post-writing activities"). Original scores and scores awarded by two independent assessors (Marker A and Marker B) are shown. *Significant differences were obtained between the pre and post writing activity reports for both Assessor A and Assessor B (by Mann-Whitney test (two group); $P<0.001$).

Figure 2 shows, that when marked using the same criteria, the reports from the most recent years (when writing activities were included in the course) are regarded as being of a higher quality and were awarded scores similar to that awarded originally to the students. However the older reports are regarded as being of lower quality and were re-graded at a much lower score compared to that originally awarded. This indicates two notable points. One is that the reports from the writing activity years (2008-09) are of a higher quality. The other is that markers obviously mark very much to the standard of the reports within each year and that once students are trained to write reports of a higher standard then a higher quality is also expected by the markers. Both assessors were consistent in their re-marking as shown above.

The surveys also asked the assessors to evaluate, using a 4 point Likert scale, a number of writing attributes within each report such as quality of figures, figure legends, analytical ability, cohesion, content, appropriate information in each section. This analysis is shown in Figure 3.

These data show the greatest improvements have been made to those areas of the report that the students themselves believed to be the focus of the activity (Table 3). This is particularly so in the case of figure legends and writing the results sections, with less improvement shown in their ability to express themselves clearly in the discussion section. Simple rules apply to writing figure legends, which once learnt can be readily applied to other examples, whereas writing a clear discussion requires much higher order scientific writing skills and further practice and experience is likely to be required.

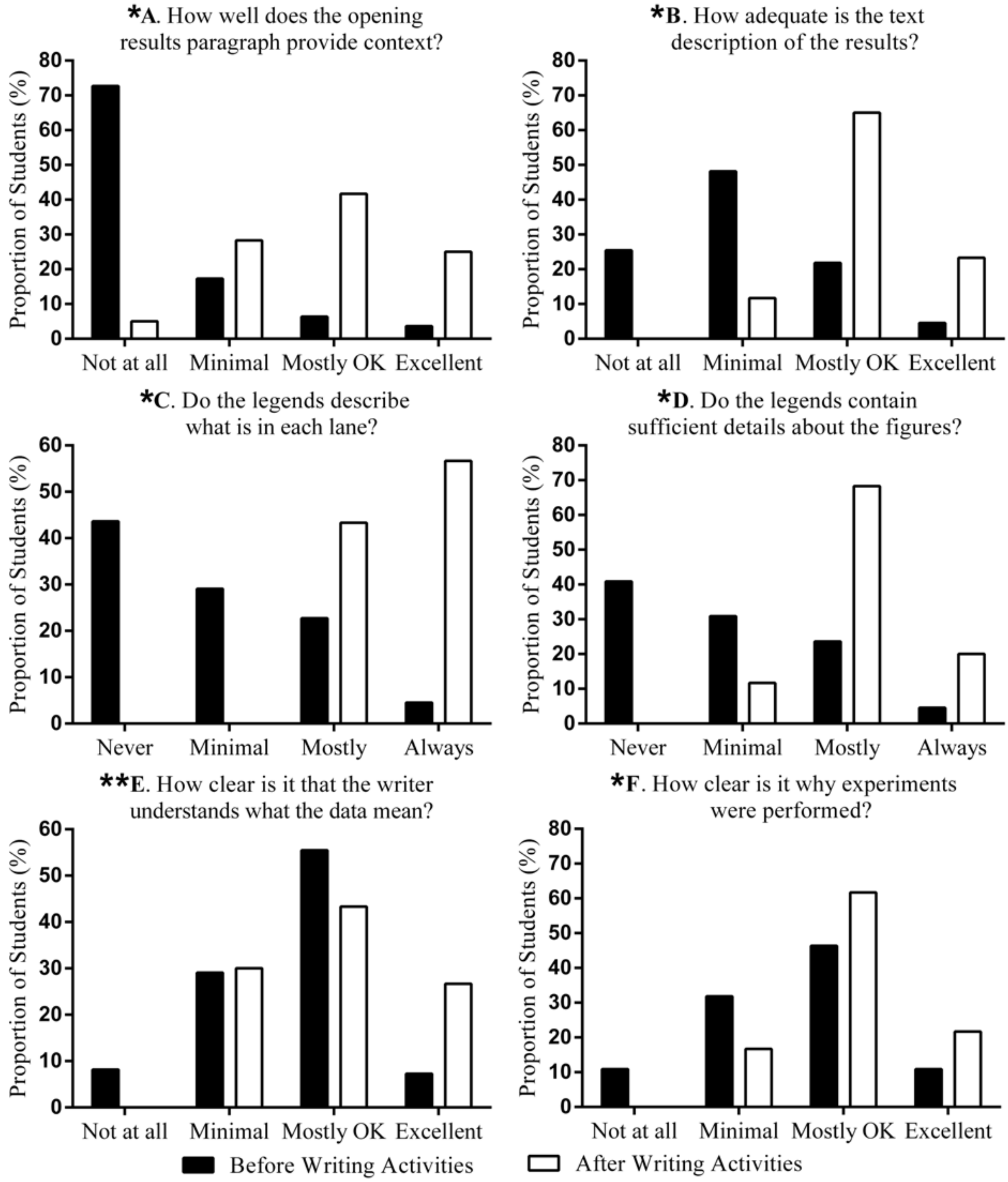

Figure 3: Assessor evaluations of specific attributes of the student written final reports. Panels A-D relate to the results section of the student reports while Panels E-F relate to the discussion sections. The Likert rating scales were: rating scale of 0 = Never/not at all, 1 = Minimal, 2 = Mostly OK, 4 =Excellent/Always). Data was pooled from both assessors: Before writing activities (N=110, derived from 55 individual reports) and After writing activities (N=60, derived from 30 individual reports). *Significant differences were obtained between the before and after writing activity reports (by Mann-Whitney test (two group); $P<0.0001$) in Panels A-D and F. Panel E exhibited a significant difference (**) at $p<0.05$.

While our study does not directly test for conceptual understanding, the independent assessors noted that the students' reports showed improved understanding of the experimental significance and outcomes (Figure 3, Panels E and F). The students also related that the writing activities helped them to better understand the purpose of the experiments (Table 5). This perceived enhanced understanding correlates with studies performed by Quitadamo and Kurtz (2007), who showed that integrating writing within a laboratory course was more effective at improving critical thinking than using traditional quiz based assessment. However, as stated above, critical thinking was not directly assessed in our study.

Conclusions

Encouraging students to embrace scientific writing training is difficult but essential. Our approach to embed writing activities into existing laboratory courses had successful outcomes in terms of enhanced writing self-efficacy and improved quality of the final reports. Students enthusiastically reviewed the writing activities and self-reported an improved confidence towards scientific writing. Analysis of their written reports suggests that the writing activities made a measurable improvement in the students' ability to generate a scientific report.

The students reported that the writing activities allowed them to approach writing the scientific report with more confidence. Confidence is known to have a positive impact on performance (Compte & Postlewaite, 2004; Sanders-Reio et al, 2014), and in our study we also found that the students' enhanced writing self-efficacy correlated with an enhanced quality of their written report. Therefore approaches that generate a perceived increased self-confidence can in themselves lead to improved outcomes.

The success of our approach is likely related to the relevance of the activities to a task that students knew they would need for both the course (to write the final report) and for their future careers. Merely adding a writing activity into a course without the students being aware of the wider significance is not likely to generate the same degree of enthusiasm noted in our courses. It has been known for some time that students do not like writing for the sake of writing (Hawthorne, 1998), and previous studies have also reported that for writing training to be effective it must be integrated into courses rather than run as stand alone courses (Jerde & Taber, 2004). Therefore any writing activities need to be relevant to the discipline in which the students are enrolled. Meaningful and constructive feedback is also essential (Moskovitz & Kellogg, 2011) to actively improve the writing and to foster a sense of self belief and pride in their writing accomplishments. This in turn promotes an enhanced self-efficacy that translates into better scientific writing skills.

Incorporation of writing activities into an existing laboratory class is an approach that satisfies the student requirements of being relevant and receiving immediate feedback. Moreover, from a staff and university perspective it is a cost effective and time efficient strategy. Most importantly the embedded writing activities were well received by the students and resulted in improved scientific writing, a skill that is acknowledged as essential to a future career in science.

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