Learning to do science: lessons from a discourse analysis of students' laboratory reports

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Abstract

Laboratory learning plays a vital and distinctive role in science education. This study focuses on the laboratory report writing of students to investigate to what extent laboratory experience mimics the process of "doing science". A quantitative analysis was performed to identify the different Moves in students' report introductions according to the Swales' (2004) CARS model, a tool that is used to analyse research articles. This model is well suited to analysing students' writing since they also follow the IMRD structure when writing laboratory reports. The results revealed that students generally use Moves 1 (topic generalization with increasing specificity) and 3 (presenting the present work) but Move 2 (establishing the niche) is absent in their physics and biology laboratory reports and physics project reports. Move 2 is central to doing science. In contrast to the laboratory and project reports, Move 2 was present in students' science research placement project reports. This paper suggests that it is better, where possible; to incorporate this aspect of doing science into laboratory programs since it gives novice learners a better understanding of genuine research processes. This study also highlights the importance of interaction between discipline specific academics and academic language units to give students a consistent message.

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Introduction

Laboratory learning and laboratory reports

Laboratory learning plays a central role in science courses as the place where students learn how to "do science" as distinct from learning the content of science. Learning outcomes associated with problem solving, critical thinking, experimental design and data analysis as well as teamwork and communication skills are typically associated with the laboratory components of courses. Hofstein & Lunetta (2003) point out the rich benefits in learning that accrue from using laboratory activities and highlight their significant place in tertiary science education.

Rice et.al (2009, p. 13) state that "*Science is about knowledge of the material world grounded in experiment. For most science academics it follows automatically from this that laboratory work must be an essential part of a science education*".

Laboratory programs, particularly project or inquiry based rather than recipe based programs, can provide students with an opportunity to perform almost all the tasks of a practicing scientist – experimental design, data collection, analysis and finally communication of their findings via a report. It is difficult, if not impossible, to provide this opportunity without a laboratory program. Anecdotally, we often hear from colleagues that reduced funding, increased student numbers and pressure on academic work hours is resulting in pressure to decrease the number of hours spent by students in laboratory, and we have been subjected to such pressures ourselves. However, some laboratory experience is still generally considered necessary for a student who wishes to become a scientist. The possible learning outcomes of a laboratory program are diverse, and may include deeper content knowledge, specific experimental skills, or more generic skills such as critical thinking. Here we focus on one particular aspect of the laboratory program, the laboratory report, and what it can tell us about how well the laboratory experience mimics the process of doing science.

Writing is a key aspect of the student learning experience in higher education. While in the sciences the skill of writing may not be considered to be as important as the skills of scientific method, writing is a valuable method of determining the extent to which students have understood scientific methodologies (Ellis et.al, 2006). Laboratory reports are one of the major writing tasks in almost all science subjects and serve the dual purpose of teaching students how to communicate as a scientist, as well as providing a way for academic staff to measure the learning achieved in the laboratory.

Scientific writing is a complex process which involves a number of skills, including interpreting, summarising and critical thinking, as well as clearly and appropriately communicating information. High competency in academic writing is crucial for success in tertiary studies (Oliver & Vanderford, 2012) and universities invest substantial resources in maintaining academic skills support units where students receive help with their writing. These units specialise in English for Academic Purposes (EAP) which can be defined as "*language research and instruction that focuses on the specific communicative needs and practices of particular groups in academic contexts*" Hyland (2002, p.2). The particular group we are interested in, in this case, is scientists, and the particular communicative task is the laboratory report.

A laboratory report, especially in upper levels, is a proto-type scientific paper, with a structure, style and vocabulary similar to that of a published scientific paper. A laboratory report typically includes components of introduction, methodology, results, discussion and references with some variations such as the inclusion of an abstract at the beginning and/or conclusion at the end or a combined section of results and discussion. Almost all laboratory reports written by students follow the IMRD (Introduction, Method, Results, and Discussion) structure, mirroring that used in the professional scientific literature. Hence the typical format of a laboratory report has the same sections as many scientific articles, and students are often encouraged to write in past tense and passive voice, as is traditional in scientific writing.

The introduction, which we will be focusing on in this paper, provides topic generalisation with increasing specificity and presents research questions, hypothesis or the aim of the experiment. We use discourse analysis to analyse the introduction sections of students' laboratory and project reports.

Discourse analysis and genre

In recent years, applied linguists and language teachers, especially those concerned with the teaching of academic literacy, have shown a great deal of interest in genre-centred approaches. The genre-based approach to teaching academic literacy simply means enhancing language competencies using content-based materials. Hence, genre-based language teaching raises learners' awareness of linguistic features and patterns associated with their specific academic genres, which enhances their effective communication skills in their discipline. For this reason, applied linguists have shown a great deal of interest in employing genre-centred approaches to the analysis of written and spoken discourses in different disciplines, as an understanding of the genre is necessary to be able to teach that genre. These approaches then inform the teaching of English for Academic Purposes by academic skills centres.

A genre comprises a class of communicative events, the members of which share some set of communicative purposes. Genre analysis is the study of how language is used within a particular setting (Swales, 1990). Science is a distinct genre which differs from other disciplines. Hence, the written communication too is distinct from other disciplines since it owns distinctive linguistic features and rhetorical structures. The basic tenet of genre analysis is that each genre, or type of communication, has its own rhetorical structure, consisting of textual units called "Moves", which are sequenced in a particular order. Further, a move has its own communicative function that can be recognized by a set of linguistic features. Each move, in turn, consists of subunits called steps (Kanoksilapatham, 2012).

Swales (1990) has developed a model to analyse the different move structures and the linguistic features of introduction sections of research articles. Since the emergence of this model, a multitude of genre-based studies has focussed on the rhetorical organisation of introductions in different academic disciplines, including medical research articles, computer science journals, engineering sub disciplines, biochemistry and so on (Nwogu 1990; Samraj 2002; Safnil 2013; Kanoksilapatham, 2005). Later, based on the results generated by a large number of subsequent genre-based studies, the 1990 model was revised in 2004 (Kanoksilapatham, 2012). This research has informed the teaching of scientific writing as a genre by academic literacy experts.
Much research has been done on academic discourses analysing the different genre types used by academic experts and how such specialised texts are realised in particular disciplines (Chahal, 2014). Bhatia (1993) states that teaching academic writing has accordingly been reconceptualised as an endeavour to develop discursive competence in students and their ability to participate in the different discourse modes of their academic community.

Here we have used this genre analysis approach with the revised Swales' model to identify different moves in science laboratory report introduction sections. As the particular model used is based upon expert writing in science (published articles), by applying it to students' laboratory reports we are able to see to what extent the work of novices differs from that of the experts. By highlighting differences between novice and expert writing, we hope that this paper may contribute to improved pedagogies for the teaching of scientific writing both by EAP units as well as within science teaching.

Perhaps more importantly, at least to science academics, the differences allow us to see how the experience of the laboratory program differs from that of the experience of "being a scientist". If such differences exist, then the role of laboratory work as teaching the practice of science may need to be reconsidered.

Method

The Sample Set

A total of 36 reports were examined for this analysis. These were drawn from across disciplines, and from different year levels, and came from two different universities. Sixteen biology laboratory project reports were used, with eight drawn from second year and eight from third year biology courses. The biology projects on which the reports were written consisted of a series of linked experiments. While the series of experiments was labelled a "project", each experiment was largely recipe driven, with the learning of new techniques the main aim of the experiments, as well as supporting the theory learnt in course lectures.

Six first year physics laboratory reports and six first year physics laboratory project reports were used. The laboratory experiment reports were written on an experiment which was somewhat inquiry based, with the experimental aims given to the students, but no detailed recipe for how to perform the experiment or analyse the data. The physics laboratory projects were more strongly inquiry based, with students working in groups and selecting their own topics, formulating their research questions or hypotheses, and designing their own methods. These projects were, generally, undertaken in the teaching laboratory with the usual demonstrator staff supervising the projects.

Finally, eight third year science experimental research placement project reports were analysed. The students undertaking these projects are the more able students, who are placed, individually, with an academic supervisor and work with that academic's research group on some aspect of that group's research for a semester. The projects covered a range of science disciplines including physics, chemistry, oceanography and ecology. The research project itself is the entire course, rather than being part of a course with other significant components of contact time and assessment.

The other laboratory reports analysed (first year physics experiment and project, second and third year biology project, as described above) were all based on a single component (one experiment or series of experiments) of a given course which also included lectures, tutorials, exams, etc.

Swales CARS Model

The methodology used here is based on the Swales' 2004 (Kanoksilapatham, 2012) model for research article introductions. As stated in the introduction, this is the model generally used by teachers of English for Academic Purposes.

A quantitative analysis was done to check whether the Moves and the steps in the Swales' CARS (Create-A-Research-Space) Model are prominent in laboratory report introductions. The CARS model was chosen for this study since it elucidates how the texts are organised and it has been the predominant analytical tool used in the examination of introduction components of research articles.

According to this model, introduction sections include three basic moves.
Move 1: Establishing the territory - provides background information for topic generalisation with increasing specificity. Research articles most often begin by establishing the importance of the general topic within which the research being reported is situated. Topic generalisation is supported by the available literature. The specificity of the current research is highlighted at the end linking to Move 2. Move 1 can be seen in almost all published research articles irrespective of the discipline.

Move 2: Establishing a niche which justifies the present study. Move 2 receives considerable attention in research articles since it is the most important section which highlights the significance of the current study or counter claiming. This is done by indicating the knowledge gap based on available literature (adding to what is known), by presenting a positive justification or counter-claiming (disputing existing literature). Move 2 is present in almost all research articles in all disciplines.

Move 3: Presenting the present work. This involves 7 steps, namely: 1.Announcing the present research descriptively, 2. Presenting the research question, hypothesis or aim, 3. Definitional clarification, 4.Summarising the methods, 5. Announcing the principle outcomes, 6. Stating the value of the present research, 7. Outlining the structure of the paper. Step 1 is considered obligatory and is always found in research articles, while steps 2 ,3, and 4 are commonly but not universally found. Steps 5, 6, and 7 are present only in some fields. The CARS model is summarised in table 1.

Table 1. Moves and Steps in Swales' CARS Model, as used to describe research article

Move	**Steps**	**obligatory/optional**
1 Establishing territory	1. providing context	obligatory, includes citations
2 Establishing a niche	1. indicating a gap	obligatory, may include citations
	2. adding to what is known	
	3. presenting positive justification	
3. Presenting the present work	1. announcing present research	obligatory
	2. presenting question or hypothesis	optional
	3. clarifying definitions	
	4. summarizing methods	
	5. announcing outcomes	present in some fields
	6. presenting value of work	
	7. describing structure of article	

In this study, the frequency of occurrence of the different moves within the introductions of the laboratory and project reports were analysed quantitatively. Each report was examined by one researcher (RAGSR) for evidence of each step listed in table 1, and where a step was noted the particular relevant sentences were highlighted. These were then checked by two other researchers, to confirm that the words used by the student did indeed represent the identified step. Where a step could not be identified, the entire introduction was read over by another researcher (KFW) to confirm that the step was indeed absent. A third researcher, trained in EAP, also checked the identified sentences to confirm that they corresponded to the steps described in the Swale's model (table 1).

Results were tabulated, and then compared and contrasted by report type to see whether the student writers use the same moves as experts and also to identify any differences between the different types of reports.

Results

The results of the analysis of the reports are summarised in Table 2. The fraction of reports in each sample which includes each step within each move is given, as well as a general summary of whether that step was present or absent

Table 2. Frequency of occurrence of different moves for each sample of student reports

Move/Step	Biology	Physics Lab	Physics Project	Research Placement
Move 1	Present (all)	Present (all)	Present (all)	Present (all)
Move 2				
Step 1	Absent	Absent	Absent	Present (25%)
Step 2	Absent	Absent	Absent	Present (38%)
Step 3	Absent	Absent	Absent	Present (25%)
Move 3				
Step 1	Present (all)	Present (all)	Present (all)	Present (all)
Step 2	Present (all)	Present (all)	Present (all)	Present (all)
Step 3	Present (18%)	Absent	Absent	Absent
Step 4	Present (50%)	Absent	Absent	Absent
Step 5	Absent	Absent	Absent	Absent
Step 6	Absent	Absent	Absent	Absent
Step 7	Absent	Absent	Absent	Present (13%)

As shown in Table 2, the introduction sections of all the reports share some of the moves described by the Swales 2004 CARS model.

Move1: Establishing Territory

This move is present in all introduction sections in all the reports. Students demonstrate their knowledge of the field by presenting established knowledge related to the topic. Typically this starts with the broad context, then proceeds with increasing specificity towards their own experiment.

For example:

> *Next generation Sequencing (NGS) technology enables the whole genome to be sequenced quickly.*
>
> *We mapped the alex20 mutation to a specific region of chromosome 4.*

In some cases students cite relevant literature to demonstrate their knowledge, in others only their course laboratory manual.

Move 2: Establishing a niche

This move is absent in all the student laboratory reports for single experiments or laboratory projects which were components of courses.

In contrast, 87.5% (all but one) of the science research placement project reports involved this move either by indicating a gap, adding to what is known or by providing a positive justification of the current study.

For example:

> *Whilst its distribution is relatively well studied, very little is known or understood of the factors, such as climate, that controls it.*
>
> *The phosphorescence that results from the triplet-singlet transition is at the core of study for this research and is of particular interest as it has not been extensively studied or measured. Additionally, spectral hole burning within this region has not been previously achieved.*

Move 3: Presenting the present study

Step 1, describing the present research, is obligatory in research articles and is present in all the reports. Steps 2, 3, and 4 are considered optional for research articles, but step 2 is also present in all the reports. Step 4, which is summarising the method, can be seen only in 3rd year biology laboratory reports. This was the only difference between the biology and physics laboratory reports. Steps 5, 6, and 7 are probable in some disciplines, but all of them are absent in the sample of physics and biology laboratory reports and research project placement reports that we investigated.

Discussion and Implications

A laboratory report is generally structured in much the same way as a scientific article, and students are taught from high school onwards (Champion et al 2014, Bird et al 2015) that this is how reports are to be written. This is part of the induction of students into the academic discipline of science. Becoming fluent writers within the genre is an important part of becoming practitioners of the discipline.

The reports that we have analysed reflect, in general, the broad structure of expert writing in the field (IMRD structure), as well as many of the detailed moves and steps. We find that within the introductions Moves 1 and 3 are generally present, and in this the novice (student) writing mirrors that of experts in the field. We note, however, that steps 5, 6 and 7 of Move 3 are absent in the students' work. This may be because of the disciplines that the students are studying – biology and physics for the laboratory programs, biology, physics and chemistry for the research projects. According to Swales (2004) these steps are optional in introductions of research articles, and hence may be absent from the novice work because they would also be absent from expert work in that discipline. In addition, given the clearly defined and generic structure of the laboratory reports, step 7 (outlining the structure of the report) is completely unnecessary.

The laboratory project and experiment reports depart significantly from the CARS model for research articles in the absence of Move 2 (identifying the niche). This is not surprising when considering the physics experiment reports and the biology laboratory project reports. The experiments which these reports were based on were clearly defined in terms of experimental aims for the students. The work done was novel to the students themselves, but did not add to the body of knowledge within the discipline – there was no niche to be identified. This is generally the case for undergraduate laboratory programs. Hence, this move is, by necessity, absent from typical undergraduate laboratory reports because the work done by the students is not novel.

This is not to say that the students are not making discoveries or being inventive, or that there is no genuine inquiry occurring, as the processes used by students are enquiry based, even if the content is not novel (Kirkup et al 2016). In the first year physics laboratory course for which reports were analysed the students were generally given the experimental aim but no detailed method. The question was posed for the students, but students had to work out how to answer it themselves and were thus required to engage in experimental design. This process does mirror the act of doing research – once the question is identified, we still need to figure out how to answer it.

The first year physics projects are open ended and student driven. The stated aim of these projects is to provide students with a research experience, in which they are self-motivated and self-directed. Intended learning outcomes include time management and interpersonal skills as well as experimental design, data analysis and report writing. It is up to students to identify a question they wish to answer or formulate a hypothesis they wish to test, and they are required to state their question or hypothesis before beginning their project. Hence it is, in principle, possible for students to identify a gap in the literature. However, none of the reports analysed from this group included Move 2. This could be because none of the projects actually did contribute new knowledge to the field (they were, after all, first year projects) or because it did not occur to the students that they needed to be able to identify a niche in their final report. General instructions on how to write a report were provided, but these did not specifically require the students to identify a niche, nor did they work with EAP practitioners who might have pointed out that such a step is normal in professional science writing. While these projects in many ways mirror the real processes of research, including project proposals for a research budget, risk assessments, etc, this crucial aspect of research identifying a question worth answering and positioning it within the literature is neglected.

In contrast, all but one of the reports from the third year research placements included Move 2. The student authors of these reports worked directly with academics on the academics' own research and it is likely that in most cases the niche was identified by the academic, rather than the student themselves.

The purpose of these projects was to provide the students with genuine research training which also contributed to the research output of the group. Hence these projects often result in a research article being published, typically co-authored by the student and their supervisor and in some instances by the student only. To be able to produce a publishable research article, Move 2, identifying the niche, must be done as it is an obligatory Move. By necessity, therefore, the student authors of these reports must be able to write this Move, even if they have not themselves identified the niche. This implies that they are at least able to recognise the importance of identifying a niche, even if they have not done so themselves as yet.

To be able to identify a niche requires some expertise in the field. Typically fourth year (honours) students work on a project in their supervisor's area of expertise, with the research question determined by the supervisor. This may continue into Ph. D research, where again the niche has been identified by the supervisor rather than the student. However, at some point in their career, a working scientist must develop the skill to identify a niche and pose a research question of their own. This is an obligatory Move not only in research articles, but in grant applications and even applications for ethics approval. Hence it needs to be incorporated in some way into the training of scientists.

There are two significant implications of the absence of Move 2 in student work. First, as science academics and vocal proponents of laboratory programs, we may need to reconsider our claims that laboratory programs prepare students to do research – to "be scientists". We do not doubt the value of laboratory programs to help students develop necessary skills such as experimental design and data analysis, as well as the generic skills of critical thinking and teamwork that go along with that. However a standard laboratory course, even a highly inquiry based one, does not appear to be complete preparation – it does not prepare students to identify a niche and pose a question worth answering, and may not even alert them to the need to do so. Preparation to be a practicing scientist may not be an explicit aim of all laboratory programs, but where this is the underlying aim, then the skill of being able to identify a niche is one that should be considered.

It may be that this is not possible for large undergraduate cohorts, and needs to wait for a more genuine research experience such as an undergraduate research placement, honours, masters or Ph.D project. In effect, an internship or "work integrated learning" experience with working scientists, such as is currently being championed by the office of the chief scientist (Prinsley and Baranyai, 2015). While disciplines such as engineering and IT have student placements in industry to teach students important skills that are hard to learn in the classroom, such placements are uncommon in science. In science, undergraduate research placements may perform the role of work integrated learning, where otherwise such learning is delayed until the fourth year project which is not undertaken by all science students.

Second, the CARS model described in table 2 reflects the understanding of scientific report writing as held by EAP practitioners. EAP programs often include teaching materials to help students to write an effective introduction by identifying rhetorical structures. Based on the Swales (1990 and 2004) CARS (Create a Research Space) model, extensive research has been performed on research articles namely, medical research articles, computer journals, engineering sub disciplines, biochemistry article introductions and humanities subjects (Nwogu,1990; Samraj,2002; Safnil,2013; Kanoksilapatham, 2005). These discourse analysis studies show that these moves tend to be similar across disciplines. Hence, EAP practitioners tend to use these Moves and steps when teaching the format of general scientific writing. But, there may be a mismatch between this model and what we as science academics, the people who set the task and mark the students' work, perceive the appropriate structure of a report to be. If this is the case, then students may get conflicting, and hence confusing, advice from different sources. Academics and EAP practitioners need to communicate and work together to ensure that we give students consistent messages about what we want and what is valued in our discipline, so that our students can become effective writers and practitioners within the discipline.

Finally, an analysis such as this, coming from a discipline (linguistics) outside of science can show us new ways of looking at our discipline and make us reconsider some of our claims and assumptions about our disciplinary practices. It demonstrates the value in stepping back and looking at ourselves through others' eyes. Increased interaction between scientists and people studying the discipline from outside may yield useful fresh perspectives, which contribute to our research and teaching practices.

Conclusions

Several conclusions can be drawn from this study. Results showed that move 2 (establishing a niche) is absent in laboratory and project reports of the first, second and third year undergraduates taking laboratory programs as part of their coursework. There could be several reasons for this. The experiments were designed by the teachers to give hands on experience to the students about the concepts that they learn in lectures, as well as developing experimental skills. This is novel to the students but it does not add to the body of knowledge in that particular discipline. In contrast, students taking part in research placements were able to identify a niche for their work. As establishing a niche – identifying a research question worth answering – is an important skill for scientists, we suggest that it would be beneficial if this could be incorporated into undergraduate programs, for example by the use of research placements, which act as "work integrated learning".

This study also highlights the importance of the interaction between discipline specific academics and EAP practitioners to give a consistent message to the students about what is needed and valued in each discipline. The model used in this study is generally accepted in almost all disciplines, hence EAP practitioners, from whom students seek assistance in academic writing, tend to follow this model. If there is a mismatch between this model and the model used by science academics, it should be discussed to ensure students receive a consistent message.

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