It's all foreign to me: learning through the language of genetics and molecular biology

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Introduction

"The conformational change induced by CRP binding to its specific DNA motif leads to stable binding of bacterial DNA-dependent RNA polymerase to the upstream lac DNA sequence, and hence allows the transcription of the lac Z, Y, A genes to proceed ….."

Molecular Biology and *Genetics* are taught to undergraduate students at the second and third year level of their University of Canberra degrees. The assumption is, particularly for the third year students who have passed previous units/subjects in fundamental chemistry, biology and biochemistry, that the concepts and many of the details confronted in the more specialised discipline areas like genetics/molecular biology will be familiar. Anecdotally, this has not been true and the specialised language, for a majority of students, leads to a loss of engagement with the content of the unit and hence the learning outcomes. While there are issues around retention of knowledge from previously studied foundation units, it seems a bigger problem is that students find the lecture material, readings and other study material impenetrable.

Researchers have acknowledged the importance of language in science education for over 40 years. The history of thinking in this field has been reviewed by Wellington and Osborne (2001), and these authors go so far to suggest that language is of primary significance to learning science, a situation that may have been deflected traditionally by the focus on practical/laboratory work in science curricula. Furthermore, previous research in looking at the language of science (Gardner 1972; Gardner 1975; Pickersgill and Lock 1991) suggested students have problems with both technical and non-technical vocabulary especially with the logical connectives. While these studies did not set out to examine the retention of scientific vocabulary, there was recognition that the comprehension of difficult scientific articles necessitates the retention and understanding of both types of vocabulary. These studies promoted the idea that language understanding, as well as reflective and active reading, are skills that must be taught.

The aim of this study was to investigate whether learning of the genetics/molecular biology unit content, and associated concepts, was enhanced through the application of educational techniques normally found in language learning. To determine the efficacy of this mode of teaching, quantitative and qualitative analyses were performed to compare the 2005 (experimental) cohort with the 2001-2004 student cohorts who studied *Genetics* under a traditional transmissive mode of delivery.

Methods

Survey procedures and student profile

In order to establish what students do know when reading scientific articles, a pre-project questionnaire was administered to 32 students consisting of 24 females and 8 male students in the 2005 cohort. The average age of the student body was 23 years of age. Questionnaire data reviewed that 21/32 students highlight the difficult words in the article and try to read and read again if they encounter something they do not understand. Most of the difficulties encountered were: (1) not understanding the terms, and (2) having difficulty in maintaining focus. Students were also asked to make suggestions to improve their reading. Many of them requested shorter articles and a provision of terms, definitions and abbreviations.

The pre-experiment questionnaire results suggest that this group of students might be using too few strategies in reading; and secondly when reading, too few modalities were used. In other words, students in this unit were rather passive in the way they learn. Not only did they appear to learn passively, it was also difficult to ascertain whether there was any active construction of knowledge involved at all. Learning seemed to involve a process of reading with a pen. For the student body involved in this experiment, there were a large number of students who were school leavers.

Guided by the research of Gardner (1972, 1975) and Pickersgill and Lock, (1991), a range of techniques were used to teach or reinforce active reading and subsequent reflection skills to students who were set a number of readings from the primary literature in genetics and molecular biology. Underpinning much of this process was a focus on translating scientific words/terms as if they were from a foreign language. Specific techniques employed in this study are outlined in the next section.

Experimental techniques applied to encourage language learning

To encourage active learning, a number of techniques used in language teaching and education were introduced over 13 weeks. The techniques employed were:

Table 1. The language learning techniques used in the experiment

1. Small group discussion in tutorials
2. Breaking down long words to aid memory
3. Warming up activities such as match definitions to concepts
4. Online exercises
5. Providing lecture notes and exercises on *WebCT*
6. Online assessment
7. Connecting different concepts
8. Consistently revising previously learned concepts in tutorials through group work
9. Using the structure of scientific articles to guide the understanding of what is important and what is not in readings and tutorials through group work
10. Giving students opportunities to put forward their point of view in groups
11. Provide tutorial questions to stimulate tutorial discussions

During the 13 week semester in semester 2 2005, the educational lecturer who is the partner in this project attended every lecture and tutorial and participated as a co-teacher. To further enhance learning, a genetic learning website was set up in which weekly exercises such as crosswords, matching, fill-in-blanks exercises were provided for individual study.

At the end of the experimental period, a post-experimental questionnaire was also administered to each student. This questionnaire consisted of questions related to the design of the unit in general, the 11 techniques listed in Table 1 and several related open-ended questions.

Quantitative measures and statistical analysis

To evaluate the effectiveness of the above-described techniques, the achievement of the 2005 (experimental) cohort was compared to earlier student cohorts (2001-2004) who studied *Genetics* under a traditional transmissive mode of delivery. Comparative performance on common assessment items over the 2001-2005 periods was investigated (descriptive statistics and unpaired Student t-test), and analysis on the progression of the 2001-2004 versus 2005 students to higher final grades (P ➔ CR / CR ➔ DI) (Chi-square χ^2) was investigated. Comparison of student performance in *Genetics* (final mark from 100) with their overall degree achievement, as reflected by degree Grade Point Average (GPA), was the subject of correlation (r) analysis for each year cohort who studied *Genetics* under a traditional approach (2001-2004) or the language-centred approach (2005). Students were analysed individually and then assigned to grade/year cohorts for correlation analysis.

Results

Quantitative data

In terms of descriptive measures to compare the performance for *Genetics* students who had experienced traditional modes of university instruction versus language-centred instruction, longitudinal analysis of overall grades and group performance on individual assessment items was considered. Of immediate interest was how the 2004 (traditional) cohort compared to the 2005 (language) cohort on the end-of-semester theory examination. The examination questions were identical for both the 2004 and 2005 students, with a two-hour paper comprising twenty multiple-choice questions (20 marks from a total of 60), four short-answer questions (20 marks from 60) and an essay (20 marks from 60).

Using t-test analysis (degrees of freedom = 5, two-tails, equal variance) no significant difference was found on overall examination performance between the 2004 (traditional) and 2005 (language) student cohorts ($t = 0.80$, $p > 0.75$). Analysis of the examination results by individual sections (e.g. multiple choice) also did not show any significant variation in performance between the 2004 versus 2005 cohorts ($t = 0.15$-0.87, $p > 0.75$, degrees of freedom = 1, two-tails, equal variance).

Analysis of longitudinal data back to the first year of *Genetics* in 2001 was also considered. The mean final theory examination mark for each year ranged from 59.3% to 65.7%. The lowest mean result of 59.3% was found for the first *Genetics* cohort who studied this unit in 2001. From 2002 to 2005, the final mean examination mark ranged from 64%-65.7 %; the 2005 language cohort had a mean final examination score of 64.7%. No statistically significant variation was, therefore, observed based on the mean final theory examination mark for the year cohorts considered. For all years examined, the structure of the final theory paper was identical with some changes to question details except for the 2004 and 2005 examinations (see above). No trends or obvious differences in the proportion of students achieving a particular final grade (Fail, Pass, Credit etc) were detected from 2001 - 2005. The rate of final grade improvement from Pass to Credit, or from Credit to Distinction was not significantly enhanced for the 2005 language cohort compared to the previous traditionally taught 2001-2004 *Genetics* students (Chi-square [χ^2] analysis).

Table 2 shows the association of student overall performance in *Genetics* with their grade point average (GPA; a weighted numerical measure of attainment across all units attempted for their degree). Hence, an association between specific performance in the individual unit *Genetics* was examined against the individual student's general academic performance, and correlation analysis then performed on student cohorts grouped according to year of study and final grade achieved for *Genetics* (Pass, Credit, Distinction). The only significant association was found (i.e., *r* value that varied significantly from $r = 0$) for the 2005 Distinction cohort; hence, overall performance (final mark from 100 after completing all assessment tasks) in *Genetics* for the 2005 Distinction students had a statistically significant association ($p = 0.045$) with their past academic performance in their respective degrees. Interestingly, this association was not found for Distinction students from the traditionally taught 2001 – 2004 groups. Low student numbers did not allow analysis by individual degree.

A conclusion, therefore, is that language-centred teaching in *Genetics* was of benefit to high GPA students in terms of allowing them to maintain their performance in an individual unit of study. Inspection of the *r*-values for each of the years analysed also suggested a much stronger association between these measures for the 2005 cohort (Table 2). For the Pass and Credit cohorts, the correlation of GPA with overall performance in *Genetics* was weak for the 2001-2004 students and the 2005 language group, with no significant variation from $r = 0$ observed for any year (Table 2).

Table 2. Correlation analysis of overall student performance in *Genetics* (2001-2005) with degree Grade Point Average (GPA). The years 2001-2004 comprised student cohorts who experienced transmissive modes of instruction while the 2005 cohort had a language-learning emphasis (#).

Final grade achieved for Genetics from 2001-2005 (n = number of students per grade/year cohort)	**Correlation Coefficient *(r)*** (Overall mark [%] versus Grade Point Average [GPA])	***p***
Pass:		
2001 (n = 18)	0.09	
2002 (n = 10)	0.14	All
2003 -2004* (n = 17)	-0.04	> 0.50
2001 - 2004** (n = 45)	0.06	
2005# (n = 11)	**-0.08**	**0.81**
Credit:		
2001 (n = 20)	0.34	> 0.10
2002 (n = 13)	0.03	> 0.50
2003 -2004* (n = 15)	0.41	> 0.05
2001 - 2004 (n = 48)**	0.24	> 0.10
2005# (n = 12)	**0.23**	**0.50**
Distinction:		
2001 (n = 11)	-0.20	> 0.10
2002 (n = 13)	0.25	> 0.10
2003 -2004* (n = 6)	0.29	> 0.10
2001 - 2004** (n = 30)	0.12	> 0.10
2005# (n = 10)	**0.64**	**0.045**

Only students who had attempted 3 semesters (36 credit points) of their degree were included.
p-values represent the significance of correlation coefficient (r) variation from r = 0 (no correlation between parameters).
A significant correlation is taken as $p \leq 0.05$ (Spearman's correlation, two-tail analysis).
* The 2003 and 2004 student cohorts were combined due to low numbers.
** Pooled correlation across the years 2001-2004 for Genetics student cohorts with no language-based instruction.

Qualitative data

At the end of the semester, a post experimental questionnaire was conducted and students were asked to evaluate the range of techniques used in the experiment. Table 3 contains the results of the questionnaire data with regards to the experimental techniques:

By adding up the percentage of students who found the techniques strongly effective, very effective and effective, it was found that techniques 5>6>8>10>1=11>7>9>2>3>4 (>: indicates one particular technique was more effective than another according to student perception).

It is interesting that while students found the provision of lecture materials online very helpful towards their study (with techniques 5, 6, 11 ranked first, second and fifth place), only 62% of the students found the online exercises on the Genetic learning web page useful. Other higher ranked techniques (8, 10, 1, 7 and 9) involved the use of group work to revise previously learned concepts in tutorials and readings; to apply new techniques such as using the structure of scientific articles to guide reading and to discuss and obtain feedback through discussion in the learning community. Most students viewed the learning through group discussions as effective. In contrast, language learning specific techniques such as breaking down words to aid memory and using warm up activities were only considered by some students as effective means of learning.

Table 3: Post-experimental data from questionnaires

Techniques	Did not answer (%)	Strongly Effective (%)	Very Effective (%)	Effective (%)	Not Effective (%)	Neutral (%)	Not Applicable (%)
1 Small group discussion.	3	9	41	35	2	1	0
2. Breaking down long words to aid memory.	0	12	44	26	18	0	0
3. Warming up activities such as matching definitions to concepts.	0	15	32	29	24	0	0
4. Online exercises with hot potatoes.	0	9	15	38	21	15	3
5. Lecture notes and exercises on *WebCT*.	0	35	50	12	3	0	0
6. Online assessment.	0	38	32	26	2	0	0
7. Connecting different concepts.	0	6	47	32	6	6	3
8. Consistently revising previously learned concepts in tutorials and in readings in group work	0	18	44	29	9	0	0
9. Using structure of scientific articles o guide your understanding of what is important and what is not in reading and lectures in group work.	0	9	53	21	15	3	0
10. Giving students opportunities to volunteer answers and different points of view in groups.	3	24	35	29	0	9	0
11. Use tutorial questions to stimulate tutorial discussions.	0	29	32	24	9	6	0

The answers to the open-ended questions in the post-experimental questionnaire affirmed the positive impact of these techniques on students. Many students felt:

- that the breakdown skills used to read journal articles were useful in every other subject;
- that building upon genetics in previous units helped them in completing other subjects such as Pathobiology;
- they develop skills in understanding scientific papers (using language exercises);
- they became much more dependent on finding answers for themselves rather than relying on being told all the time.

Discussion

According to Wellington and Osborne's experiences in the United Kingdom in science lessons in secondary school, "reading is not seen as an important part of science education. Large amounts of time are devoted to so-called 'practical work' (some of which is of dubious value: Wellington 1998) (Wellington and Osborne 2001). Furthermore, the reading that does occur is largely from the blackboard or whiteboard. In Australia, secondary school students might also be exposed to such 'practical' curricula during their secondary school years. Consequently, when these school leavers enter universities, where planned reading of scientific articles is an essential part of the curriculum, they inevitably lack the skills to read carefully and critically, and hence fail to develop a critical attitude towards content.

The effectiveness of small group activities has been proven by a large number of studies (Cooper, MacGregor, Smith and Robinson 2000; Ebert-May, Brewer and Allred 1997; Johnson and Johnson 1989; Springer, Stanne and Donovan 1999). According to the results from the post-experimental questionnaire, most students embraced group work positively. In contrast, learning through exercises on *WebCT,* or other web pages, was much less popular. Most students might have used *WebCT* as a repository for information rather than a learning tool. This might be because doing things on the net is a lone activity done by individual students rather than in a group. In this study, students certainly thought small group discussion was much more effective than studying online.

However, student resistance was detected especially in the open-ended question section in the post experimental questionnaire. One respondent expressed their concerns for these new learning strategies saying, “I believe we have learnt better how to learn but haven’t learnt the content in any level of depth”. This student’s response pointed out an area that can be improved in this research. One of the strengths of this approach was that at the end of the experiment some students walked away with a large range of strategies for reading and learning scientific materials that they can use to guide their future learning. A weakness of the approach was perhaps that in implementing such a large number of strategies all at once in such a short period of time (13 weeks), some techniques necessarily worked better than others but the effectiveness of such techniques was hard to measure and trace. In order to achieve the depth of learning that is desired by students, it may be necessary to provide students with more time to use these strategies so that they are satisfied with their understanding of a particular concept area.

Conclusion

The data collected from this study suggests that techniques from language learning and education made student learning more active and these techniques had influenced some students’ learning patterns not just in *Genetics*, but also across a number of other units. Apart from the positive impact of these techniques reported in the qualitative data, the significant correlation of the 2005 Distinction cohort’s achievement in *Genetics* with their past performance (GPA) demonstrates that these students benefited most from these techniques, and suggests that they were most likely to employ both the language learning skills and the educational techniques that supported such genetic language acquisition and application, to the understanding of scientific concepts.

Students’ positive responses towards group discussion activities suggest that future studies can be conducted to investigate how directed activities (Davies and Greene 1984) can be further used to stimulate discussion of scientific texts thus enhancing their retention of scientific knowledge. The results of this study will also guide the future application of fewer specific educational techniques to enhance language and comprehension skills.

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