Catering for the language needs of diverse first year science students

Dr. Felicia Zhang, Faculty of Arts and Design, University of Canberra, Australia;
Dr. Brett Lidbury, Faculty of Applied Science, University of Canberra, Australia,
Dr Jurgen Schulte, University of Technology, Sydney, Australia,
Dr. Adam Bridgeman, the University of Sydney, Australia,
Dr. Brian Yates, University of Tasmania, Australia and
Dr. John Rodger, University of Newcastle, Australia

Abstract

One of the emerging issues in science teaching is the changing nature and diversity of students. This Australian Learning and Teaching Council (ALTC) funded project commenced in late 2007 to address the language needs of a diverse student body by investigating and testing strategic approaches to learning and teaching in First Year sciences. This project was concerned with the acquisition of language specific to science and the implicit teaching of meta-cognitive skills required in science. Eight strategies were employed in three disciplines in five universities and positive outcomes were obtained across the board. Students' perception of lecturers' teaching ability improved. The project sustained student learning through affecting lecturer expertise in using language strategies, and is an achievable model for professional development

Introduction

Student retention and progression rates are a matter of concern for most institutions in the higher education sector (Burton & Dowling, 2005; Simpson, 2006; Tinto & Pusser, 2006), especially in the first year experience at university (for example, in the Australian context, see Krause, Hartley, James, & McInnis, 2005).

Currently, there are two broad approaches to providing extra *academic (rather than language)* support to help students succeed during their first semester at university: (1) targeting all students who wish to participate in extra learning opportunities; or (2) targeting only those students deemed to be at risk (for example, see (Miller, Gregg, & Kelly, 2000). While there are considerable resource implications associated with such broad-based schemes, they are reported to be effective (O'Byrne, S. Britton, A. George, S. Franklin, & A. Frey, 2009). However, the problem with the approaches above is that students either have to self-select or be selected for such extra academic support. This assumes that students who are not selected are all coping with their first year science study. This project questions this assumption and offers proof that as far as language in science is concerned, *all* students need support. Thus, we aim to offer language support to all students who attend lectures and tutorials thus developing an approach of academic support that supports *all* students.

The role of language in science

Specialist terminology in biology, chemistry and physics has proven difficult for most students (Wellington & Osborne, 2001). Previous research in the language of science (Gardner, 1972, 1975; Pickersgill & Lock, 1991; Wandersee, 1988) further suggests that students have problems with both technical and non-technical vocabulary, especially with the logical connectives such as 'and', 'or', 'but', and 'although'. Research into the problem of enabling students to better acquire scientific vocabulary suggests that 'technical' words make up only a small percentage of vocabulary in scientific texts and therefore pose fewer difficulties than vocabulary used in normal English as well as in a science context. For example, words that have both a scientific and everyday meaning such as ‘work’, ‘energy’ or ‘power’ can cause confusion for learners.

In this project, in order not to fall into the trap of ‘activitymania’(Moscovici & Nelson, 1998) where science instruction involves a series of disconnected hands-on activities disconnected from the “. process of searching for patterns and relationships in the world” (p. 14), we place teachers in the centre of learning by asking them to ***explicitly model*** how to test reality ‘by checking, monitoring, coordinating, and controlling deliberate attempts to execute learning activity (Koch, 2001, p. p. 760). This is why in the lectures and tutorials involved in this project, interventions were designed to increase student to student and student to staff discussions in activities which promotion sense-making rather than just completing calculations.

Gunstone (1994) argued that meta-cognition is central to constructivist perspectives of learning. This idea is reaffirmed and embraced by Yore (2006). Meta-cognition was first used by Flavell in 1976 (Flavell, 1976). He describes it in these words:

> Metacognition refers to one’s knowledge concerning one’s own cognitive processes or anything related to them, e.g., the learning-relevant properties of information or data. For example, I am engaging in metacognition if I notice that I am having more trouble learning A than B; if it strikes me that I should double check C before accepting it as fact. J. H. Flavell (1976, p. 232).

The eight strategies outlined in Table 1 below all promote some aspects of meta-cognition

Table 1: Strategies implemented in the project and the research that supported them.

Strategies	**Experimental sites**	**Meta-cognitive skills practiced**	**Research supporting the use.**
1. Small group work in tutorials using guided questions	(USyd, UC, Uni. of Newcastle, UTS)	Learning to use oral language to express and explain scientific ideas	(Kempa, Ayob, & 1995), (Ritchie, Tobin, & 2001)
2. Students are provided with a list of terms and, through the process of group work, place these terms in relation	Uni. of Newcastle, UC.	Physical concept mapping, exploring relationships between each term	Wellington and Osborne (2001), (W. M. Roth & Roychoudhury, 1994)
3 Giving students opportunities to put forward their points of view in groups	USyd, UC, Uni. of Newcastle, UTS	Creating a supportive atmosphere for idea exploration and debate	(Chin & Brown, 2002)
4. Using online language exercises such as crosswords, gap-fill (cloze) exercises and simplified scientific readings	UC	Explicit instruction, practice, applying concepts	No research discovered in science education
5. Providing stimulus questions for lecture and tutorial materials on WebCT thus encouraging students to prepare before the lecture	(UTAS, Uni. of Newcastle)	Preparation or reflection, just in time learning, online feedback	(Zhang & Lidbury, 2006)
6. Breaking down long words to aid memory by identifying prefixes and suffixes, and exploring the roots and origin of words	Uni. of Newcastle	Explicit instruction on how to acquire new vocabulary and how to see patterns in the roots and origins of words.	Wellington and Osborne (2001)
7. Using warm up activities such as matching scientific terms to definitions for revision purposes	Uni. of Newcastle	Categorising and systematising terms	(Richardson & Zhang, 2008; Richardson, Zhang, & Lidbury, 2008)
8. Using of flashcards for vocabulary revision, creating a glossary	Uni. of Newcastle, UC	-Metalinguistic maintenance	(Zhang & Lidbury, 2006)

Building on existing knowledge on pedagogical advances

Many researchers have invested a great deal of energy in investigating 'how' problem areas can be taught better or how learning activities can be organised better to enable better learner outcome in science education. In chemistry, radical suggestions for reform have been about whether to teach introductory level of chemistry from the macro and tangible, then the sub-micro atomic and molecular and then the representational use of symbols and mathematics (Johnstone, 2000). However, judging from the popular chemistry textbooks published by leading publishers, this debate is clearly not having much impact. The textbooks used in the two chemistry cohorts involved in this project, Chemistry by Blackman, Bottle, Schmid and Mocerino; and Chemistry: The Molecular Science by Moor, Stanitski and Jurs, both follow the traditional sequence in curricular design by teaching the sub-micro atomic and molecular first in conjunction with the representational use of symbols and mathematics and very rarely then teach the macro level of chemistry. However, other researchers, rather than arguing for a complete departure from the traditional sequencing of chemistry content in (Dreyfus, Jungwirth, & Eliovitch, 1990) introductory courses, utilised planned cognitive conflicts by confronting students with a phenomenon that cannot be explained with their prior knowledge (Dreyfus, et al., 1990; Nieswandt, 2001).

In physics, many studies in designing instructional sequence in concepts such as force, motion and Newton's Third Law have been carried out (Alonzo & Steedle, 2008; Halloun, 1998; Savinainen & Viiri, 2005). Analogies have also been used extensively to remediate misconceptions in physics since the early 1990(Brown, 1992; Dupin & Johsua, 1989).
In this project, activities were designed to be based on direct experience as far as possible (Boud, 1993) and reflection was seen as important in building understanding (Schon, 1987). Also, students and staff are participating in academic communities of practice (Lave & Wenger, 1991). The roles of teaching and lecturers are changing too in this project. Science lecturers worked alongside an educationalist and contributed to educational research and scholarship. Students' learning changed over two years during the duration of the study, academics' teaching also changed. The science academics involved in this project are extremely accomplished and knowledgeable individuals in their own disciplines. By participating in this project, they are positively recognizing the possible contribution education theories and practices can make to their teaching. The involvement of the educationalist is a way of establishing a mutually-beneficial learning relationship so that science academics and the educationalist can gain new knowledge from each other. The educationalist involved in the project has very little scientific background in the targeted disciplines. She, in a sense, is like a student who chooses to do science without the necessary pre-requisites.

In this model, changes in teaching approach were explored through a co-teaching or peer coaching approach (Ladyshewsky, 2006; W.-M. Roth, 1988; W.-M. Roth, K. Tobin, A. Zimmermann, N. Bryant, & Davis, 2002) in which the education/language expert shared with the science academic techniques and strategies used in teaching in a constructivist model while the science academic taught the education expert the content and pedagogy used in a particular science discipline. This coaching practice before lectures and tutorials in private between the educationalist and the lecturers was an essential element in successfully implementing the change in science academics' lecturing styles in the face to face context. During the coaching practice in private, the educationalist and the lecturers worked together to anticipate areas that students might not understand. This preparedness enhanced the delivery of the content using the new face to face protocol.

In the project, we undertook to do the following: (1) conducting an online language difficulty survey to ascertain the problems students might have with scientific language (phase 1); (2)to implement the following two protocols in teaching in all five universities. The FTF protocol consists of the following parts: (1). During each lecture, the lecturer builds into the lecture materials, short survey questions made available on Votapedia (*http://www.votapedia.com*) or audience response devices such as clickers (*www.keepadinteractive.com*) to offer feedback on lecture content. (2). During tutorials, interactive activities are introduced. Such interactive activities can include small group discussions involving the linking of concepts learned (Techniques 2 in Table 1) and activities related to technique 7, or 8 in Table 1. Language difficulty surveys results of the first phase of the project had already been reported at Herdsa 2009 and UniServe 2008-9 conferences (Zhang, Lidbury, Bridgeman, Yates, Rodger, & Schulte, 2008; Zhang, Lidbury, Schulte, Bridgeman, Yates, & Rodger, 2009).

Implementation at each university

University of Tasmania
At UTAS, in the implementation phase of the project, in 2009, Votapedia questions were used during the lectures as well as pre-lecture multiple-choice questions, in first year Chemistry. According to the main page of the website 'Votapedia is an audience response system that doesn't require issuing clickers or need specialist infrastructure. Known users can create surveys and edit the surveys on the site. Once signed on, students can participate in surveys either through mobile phones, online or through SMS (*http://www.votapedia.com/index.php?title=Main_Page*).

University of Technology, Sydney
UTS used clickers in 2009. This was complemented by small group discussions (Technique 1 and 3 in Table 1) and then students to teacher discussion in biweekly tutorials. In the ONLINE protocol, students were presented with a number of quizzes online before each lecture each week. This protocol involves the implementation of technique 5 in Table 1. In order to get away from the assumption that if students can correctly do the calculations, then they have understood the subject matter, we also introduced a 'Physics concept surveys' (Zhang, et al., 2009) which tested the language used in physics; such as 'force' in physics and the use of 'force' in real life. For example:

Meaning of 'force'
Which one(s) of the following sentences containing 'force' have meanings that are close to the meaning of 'force' in Physics:
1. I forced the box into the closet.
2. Jim was forcing the nut on the bolt.
3. I forced myself to go to class every day.
4. My parents forced me to go to college.
5. The force on the ball made it move.
6. The bomb exploded with great force.
7. I was hit by the force of the 18 wheeler.
8. She used a very forceful tone of voice.
Answers: a) 1, 2, 3, 4 b) 3, 4, 8 c) 1, 2, and 5 d) 5, 6, 7

University of Canberra
Research involving the use of interventions such as the ones mentioned in Table 1 was conducted over 2005-2009 in the unit Genetics at UC. For example, the cloze technique, also

known as the fill in the blanks or gap-fill exercise, to reading biology texts was used extensively to enable students to learn molecular biology language.

University of Newcastle
At Newcastle, Votapedia questions were used during the lectures as well as online revision exercises and tutorial activities over a period of three weeks out of a total of 13 weeks.

University of Sydney
At USyd, the first year Chemistry student body can be divided into three different cohorts, namely Chem 1001 (Fundamental Chemistry cohort with students with no HSC Chemistry), Chem 1101 (Students with HSC Chemistry) and Chem 1901 (students with good HSC Chemistry). To build in language support, the lecturer used 2-4 clicker questions in most lectures in Fundamental Chemistry. Concept development hand outs for the students to read and work on in groups during the lectures were also used.

Results of implementation from each institution

University of Technology
The final exams in physics consisted of sections on ‘Kinetics’, ‘Forces’, ‘Momentum and energy’, ‘Equilibrium’, ‘Thermal’, ‘Electricity’, ‘Oscillations, Waves’ and ‘Optics’. In 2008, the physics unit was taught entirely by the staff member. However, in 2009, the unit was taught by three different staff. Only the sections on ‘kinetics’, ‘forces’ and ‘momentum and energy’ were taught by the same participating academic. Consequently, only questions in these sections in both 2008 and 2009’s final exams can be used for comparative purposes.

Table 2: UTS Physics, semester 1, 2008 and 2009 data comparison

Year	No. of	Kinetics, %of	Momentum, %	Forces, % of full	Energy, % of full
2008	388	79.77	69.3	32.2	63
2009	478	83.33	75.1	46.3	53.5
% of change	23.19	4.46	8.37	14.1	-9.5
p-value		0.57	0.32	0.0	0.07

The information in Table 2 informs us that in the ‘kinetics’, ‘momentum’ and ‘forces’ sections, students in 2009 in this unit outperformed the students in the 2008 cohort. For instance, in the ‘kinetics’ section, in 2009 83.33% of the students achieved full marks for this section (79.77% in 2008). From the ‘momentum’ section, the increase is 8.37%. We also used the Z test to compare the 2 independent proportions and it is found that only the change in the ‘forces’ section is highly significant (p=0.000 to three decimal points).

Table 3: Achievement results by students attending lectures (n=108) and students who did not attend lectures (n=85) at UTS.

Assessment tasks	**Non-clicker group mean**	**Clicker group mean**	**Sig. (2-tailed)**
Total/100	38.41	56.20	.000**
Final exam	12.01	19.38	.000**
Lab	14.84	17.49	.000**
Test A	4.85	4.92	0.016*
Test B	2.28	2.99	0.003**
Wiley	5.15	8.46	.000**
Quiz	0.52	0.69	.001*

Key: *p<0.05, **p<0.005

The lecture and non lecture attendances groups were self-selected. Students who attended lectures used clickers as each clicker was registered under the students' student number. Setting the significance level as $p < 0.05$; the above table suggests that the 'clickers' group performed significantly better than the non-clickers group in all assessment items. Furthermore, only 18% of the students in the 'clicker group' failed the unit compared to the 68% in the non-clicker group. The non-clicker group did not include students who withdrew or did not sit for exams.

In 2008, semester one, the question 'I received constructive feedback when needed' on the Student Feedback Results (SFR) only received a rating of 2.70/5 and this lack of satisfaction is confirmed by the open ended questions section of the Student Feedback Results which showed that 50% of students' complaints centred on how and where the tutorials were run. Students tended to see them as basically just another extension of the lecture. As one student put it:

> The idea of a single tutorial for the whole subject in the lecture theatre was terrible.

In 2009, semester one, interventions not only have improved the rating on feedback to 3.56/5 with hardly any more complaints about the workshops:

> I felt that the workshops helped me more than lectures as it is more hands-on. What I suggest is that instead of having 3 hour lectures and 1 hour workshop a week, why not have 2 hour workshops and 2 hour lectures instead.

University of Tasmania

Table 4 below illustrates that the % of failures has increased slightly from 10.2% in 2008 to 8.6% in 2009, a drop of 1.6%; the Passes dropped by 8.4%; the Credits dropped to 23% in 2009, a drop of 2.2%; the Distinction increased to 17.6% in 2009, and finally High Distinctions increased by 0.2%.

Table 4: Distribution of grades for the unit in semester one, 2008 and 2009 at UTAS

grades	%08	%09	Difference in %
HD	9.7	9.9	0.2
DN	10.2	17.6	7.4
CR	25.2	23.0	-2.2
PP	31.4	23.0	-8.4
TS	7.5	5.4	-2.1

Table 5: Distribution of grades for the unit in semester two, 2008 & 2009 at UTAS

grades	%08	%09	Difference in %
HD	10	10.4	0.4
DN	13.9	21.6	7.7
CR	29.2	23.0	-6.2
PP	22.5	20.3	-2.2
TS	6.2	6.8	+0.6

According to Table 4 and 5's figures, there were beneficial changes to student grades. The consistent increase in the number of students obtaining Distinctions in both semesters in chemistry at UTAS seem to suggest that students who are above pass level tended to benefit from the language strategies implemented even though there is a slight increase in failures (TS=+0.6) in semester 2 in 2009.

In the Student Evaluation of Teaching and Learning (SETL) surveys conducted at the end of semester one and two, in 2009, the use of 'Votapedia' concept tests and the extensive feedback for the online non-assessable 'concept tests' were evaluated.

Table 6: SETL survey results for Chemistry 1A and Chemistry 1B in 2009 at UTAS

Items	Subject	N	No answer %	Strongly agree %	Agree %	Neutral %	Disagree %	Strong disagree %
1. I value the feedback on my understanding gained by the use of in lecture 'votapedia' questions	Chemistry 1A	139	8	12	38	33	7	2
	Chemistry 1B	117	21	5	27	34	9	4
2. The non-assessable 'concept tests' conducted on myLo helped me answer the weekly assignment questions	Chemistry 1A	139	0	23	42	20	13	2
	Chemistry 1B	117	0	16	53	18	11	2
3. The extensive feedback available when I make an incorrect response in the non-assessable 'concepts tests' are helpful	Chemistry 1A	139	0	37	46	11	5	1
	Chemistry 1B	117	3	31	48	16	1	1

Table 6 shows that most students agreed that Votapedia concept questions are useful during lectures. However, 15% of the students would like more connection between the online concept questions and the Mylo assignments. This view was also confirmed in the SETL surveys.

University of Canberra

The results of the Canberra study have been published (Zhang & Lidbury, 2006). In short when examining student performance at an individual level, an interesting association was found between performance in genetics and individual student performance across their whole degree measured by grade point average (GPA), but only for the Distinction students.

University of Newcastle

Table 7: Distribution of grades for Biology 1002 in semester two, 2008 and 2009 at Newcastle

grades	%08	%09	Difference in %
HD	0.84	12.96	12.12
DI	8.02	20.65	12.63
CR	16.88	32.39	15.51
P	50.21	21.46	-28.75
F	24.05	12.55	-11.5

As show in Table 7, significant increases were made in HD, DI and CR grades and the number of P grades reduced by 28.75% and Fail grades by 11.5%.

University of Sydney

The content of the exam in 2009 was different from 2008. Only a number of multiple choice questions in both exams were common and therefore could be compared. Consequently, only results on Fundamental Chemistry are reported below.

Table 8: Distribution of grades for the unit in semester one, 2008 and 2009 at USyd

MCQ question no.	average marks 08	average marks 09	Difference in marks
19	35	41	6
20	56	60	4
21	79	82	3
22	68	66	-2

23	91	92	1
24	**54**	**83**	**29**
25	80	84	4
26	75	78	3
27	92	91	-1
28	**78**	**86**	**8**
29	**32**	**47**	**15**
30	**92**	**93**	**1**
31	**81**	**94**	**13**
32	60	72	12

As shown in Table 8, increases in Q24, 28, 29, 31 and 32 are most probably caused by intervention strategies deployed. According USyd's Unit of Study Evaluation (USE), there was a marked improvement in Q3 ("This unit of study helped me develop valuable graduate attributes") from 3.30 to 3.51/ 5. This is most likely to be due to the report writing activity in the labs. There was also a marked improvement in Q12 ("Overall I was satisfied with the quality of this unit of study") from 4.16 to 4.23 /5. Comments from students include:

- we learnt concepts through thinking. Better than being told.
- those clickers poll things were good.

Conclusion

In conclusion, the evaluation of the implementation of project interventions showed:

- Students demonstrated better achievement scores at every university and in every discipline;
- the retention rate for each subject in the discipline, in most cases, improved; and
- students' perception of lecturers' ability to teach has dramatically improved.

The project has demonstrated as having sustainable impact, in the long term, on student learning through affecting lecturer expertise in using these language strategies. Furthermore, the project has achieved excellent results in building a successful and achievable model for a sustainable professional development of academic staff. Project deliverables such as guides on activities used, Votapedia questions and questionnaires are made available to the Higher Education sector on ALTC-exchange under the group name 'Language Strategies in Science teaching'.

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