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Embedding high impact education practices in first year science: a cross-disciplinary cross-institutional partnership

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Abstract: *This paper reports on an Australian Learning and Teaching Council (ALTC) funded project which aims at addressing the language needs of a diverse student body by embedding high impact education practices in first year sciences in five universities: the University of Tasmania, the University of Canberra, the University of Technology Sydney, the University of Sydney and Newcastle University. The disciplines covered by the project are Biology, Chemistry and Physics. In semester 1 2009, active learning strategies such as the use of Votapedia (www.votapedia.com) and online pre-assignment concept questions were implemented at two of the sites. This paper reports on student achievement results obtained from first year Chemistry (UTAS) and Physics (UTS) student cohorts in semester 1 2009. This data has been compared to data obtained in semester 1 2008. Early analysis suggests that the combination of techniques listed above, introduced in lectures and assignments, has led to improved achievement in students' overall grades and student satisfaction, as well as changes in disciplinary lecturers' teaching practices.*

Keywords: *first year science teaching, role of language in science teaching, active learning skills*

Introduction

Specialist terminology in Biology, Chemistry, and Physics has proved difficult for most students (Wellington & Osborne, 2001). Students have difficulty recognising where a concept begins and ends and therefore cannot differentiate concepts (Scott, Asoko, & Leach, 2007). Zhang and Lidbury (2006) identified difficulties with language as contributing significantly to problems students experience in studying Genetics. The language of the discipline becomes crucial in developing a context-based experience of learning (Carlsen, 2007; Moore, 2007).

The disciplines covered in this project are taught by lecturers who hold a broadly constructivist view of learning (Bruner, 1986; Tobin, 1993). In this view of learning, learners are considered to bring different conceptualisations, intentions, styles and approaches to the learning situation (Kolb, 1984; Marton, Hounsell, & Entwistle, 1984; Perry, 1988). Students' active engagement in learning activities is also an essential ingredient. Furthermore, these activities should be based on direct experience as far as possible (Boud, 1993) and reflection is seen as important in building understanding (Schön, 1987). Finally, the work of Lave and Wenger (1991) stresses the importance of situated learning. As students and staff are participating in academic communities of practice, the teaching space is no longer a site for the transmission of knowledge but rather a site for social practice. To be included in such a social practice environment, the language of that environment must be learnt (Brown & Ryoo, 2008). Thus in this study, we seek to implement language oriented strategies (Table 1) developed by Zhang and Lidbury (2006) in first Year Biology, Chemistry and Physics lectures and tutorials in order to evaluate the impact of these methods on student learning. The project is ongoing and parts of it have been reported elsewhere (Zhang, Lidbury, Bridgeman, Yates, Rodger, & Schulte, 2008). This paper will report on results of the intervention strategies applied to first year teaching in Physics at the University of Technology Sydney (UTS) and Chemistry at the University of Tasmania (UTAS), Australia in 2009.

Table 1: Proposed language oriented techniques to be implemented in the project

1. Small group work in tutorials using guided questions.	6. Attaching sound files to vocabulary.
2. Students are provided with a list of terms and, through the process of group work, place these terms in relation to a set of definitions.	7. Breaking down long words to aid memory by identifying prefixes and suffixes, and exploring the roots and origin of words. (UTAS, USyd, Newcastle)
3 Giving students opportunities to put forward their points of view in groups.	8. Using warm up activities such as matching scientific terms to definitions for revision purposes. (Newcastle)
4. Using online language exercises such as crosswords, gap-fill (Cloze) exercises.	9. Use of flashcards for vocabulary revision. (Newcastle, USyd)
5. Providing stimulus quizzes for lecture and tutorial materials on WebCT thus encouraging students to prepare before the lecture.	10. Role playing: students practise conveying complex scientific discoveries to the public. (Newcastle)

This project has also investigated the value and effectiveness of a peer-assisted teaching development approach. In this model, changes in teaching methods are explored through a co-teaching or peer coaching approach (Ladyshevsky, 2006; Roth, 1988; Roth, Tobin, Zimmermann, Bryant, & Davis, 2002) in which the education/language expert (in this case Felicia Zhang) shares with the science academic techniques and strategies used in teaching in a constructivist model while the science academic teaches the education expert the content and pedagogy used in a particular science discipline.

Characteristics of the students

Students undertaking tertiary studies in science are a highly diverse group. For instance, at the University of Sydney (USyd) in 2008, there were 969 students from various faculties in the first year Chemistry cohort. Three-hundred and eighty eight students had little or no pre-tertiary Chemistry while 116 students had very high Universities Admissions Index (UAI) Chemistry scores, with scores greater than 98 for Veterinary Science students. With such a diverse group there is, naturally, a wide range of interest in and aptitude for the subject. Such diversity is typical in cohorts in Biology, Chemistry, and Physics at the participating Australian universities in this project.

Methodology

The project was conducted over 2008 and 2009. In 2008, the control part of the project, no intervention took place except the implementation of online language difficulty questionnaires. During this phase, lecturers taught the subject matter as they would normally and students were assessed in the normal fashion. Assessment data collected during 2008 constituted baseline data to which data from the experimental phase of the project in 2009 was compared. Student cohorts in 2008 constituted the Control groups of students. Students in 2009 in the participating universities constituted the Experimental groups of students.

During 2009, interventions took place at UTS in Physics and UTAS in Chemistry. In this second stage of the project the language expert (Felicia Zhang) worked alongside the science lecturers to find the best possible ways of implementing the strategies listed in Table 1. Having identified in Stage 1 of the project that there is a gap in students' understanding of common scientific words (Zhang et al., 2008), the intention was to enhance student awareness of the language used in each discipline, perhaps by *inspiring* them "to recognize ... [that scientific discourses are] ... a specialized subset of ordinary language, requiring constant alertness to precision and the possibility of idiosyncratic meaning" (Jacobs, 1989, p. 398). In order to 'inspire' students, the intention was to implement a range of language specific education techniques (1) to alert students that precision of these terms in science is important and (2) show them how to check that they are being precise when using these terms. Zhang and Lidbury (2006) implemented a range of language specific educational techniques to encourage such thinking. Results of Zhang and Lidbury's (2006) study suggested that students favoured the use of small group work to acquire difficult and abstract genetic concepts. Considering this, the decision was made to implement firstly a face to face (FTF) learner-centred, interactive lecturing protocol and secondly online content and language support for learners (ONLINE) in the experimental stage of the project.

The FTF protocol consisted of the following phases:

1. During each lecture, the lecturer built into the lecture materials, short survey questions made available on votapedia (<http://www.votapedia.com>) to offer feedback on lecture content;
2. During tutorials, interactive activities were introduced. Such interactive activities included small group discussions involving the linking of concepts learned (Technique 2 in Table 1) and activities related to Techniques 7, 8 or 10 in Table 1.

The Votapedia tool (www.votapedia.com) was used at UTAS in first year Chemistry in semesters one and two, 2009. 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 web site. Once signed on, students can participate in surveys either through mobile phones, online, or through SMS. Both online and through mobile phones are free to the students but there is a charge through SMS" (http://www.votapedia.com/index.php?title=Main_Page). At UTAS, when this was implemented in the lecture theatre, only mobile phones on a Telstra plan could get a signal so only students with these phones could participate actively. Other students voted using a show of hands.

First year Physics at UTS used clickers (<http://educause.edu/ir/library/pdf/ELI7002.pdf>) in 2008. The results on the use of clickers at UTS (Schulte, 2008) suggested that their use enabled a sustained participation in lectures from the beginning till the end of the semesters. However, survey results suggested that even though students felt the feedback they obtained from the use of clickers aided their on-the-spot understanding, the feedback could be better used as diagnostic tools so that long term more structural change can be implemented to help the students to self-structure their study (Schulte, 2008). In 2009, due to a large increase in student numbers in semester 1 (an increase of about 100 students thus raising the final student count to 530), clickers were not used but a show of hands was used to determine student responses. This was complemented by small group student-to-student group discussions (Technique 3 in Table 1) and then students-to-teacher discussion in biweekly tutorials. Only one hour was available in these tutorials. Unfortunately, at UTAS, due to institutional constraints, small group activities could not be built into the weekly tutorials.

In the ONLINE protocol, students were presented with a number of online quizzes before each lecture each week. This protocol involved the implementation of Techniques 4 and 9. The research team involved in Physics and Chemistry created, implemented, and collected data on a set of language specific online quizzes for the respective disciplines in 2009.

In 2008 and 2009, the Physics assignments deployed through the *Wiley Plus* website consisted mainly of calculation type questions. Below is an example:

- On a dry road, a car with good tyres may be able to brake with a constant deceleration of 5.28 m/s^2 . (a) How long does such a car, initially travelling at 24.4 m/s , take to stop?
(b) How far does it travel in this time?
- (a) Number: 4.62 Units: *s*
(b) Number: 56.38 Units: *m*

In order to get away from the assumption that if students can correctly do the calculations, then they have understood the subject matter, we introduced 'Physics concept surveys' which tested the language used in Physics. At UTS in this unit, there was only a one-hour tutorial available every fortnight for the students. During those tutorials, the lecturer incorporated multiple choice and concept questions related to language use. The concept questions were created specifically to test students' understanding of particular concepts 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.
- a) 1, 2, 4, 3
 - b) 3, 4, 8
 - c) 1, 2, 5
 - d) 5, 6, 7

During semester 1 in 2009 at UTS, two calculation type tests and a final exam were conducted. This enabled the results of those tests and the exam to be compared with similar tests and an exam used in semester 1 2008. In addition to this, a Physics Concept survey was also administered. This survey combined 16 questions related to definitions of physics concepts such as 'force' and 'momentum' and 25 questions on 'thermodynamics' taken from Yeo (2001). The survey was completed by 269 students. However, because this test was not administered in 2008, no comparison was possible.

At UTAS, multiple-choice questions with full feedback were provided to students on our Learning Management System (MyLO). Each of these quizzes were similar to the Physics Concept surveys discussed above and the questions were designed to test students' understanding and to provide helpful and detailed feedback to correct any mis-conceptions. In order to ensure full participation by students, access to the weekly assessable assignments was made conditional on the completion of these quizzes. However, students who did not wish to participate in the project had an opting out option which they could select. Once this option was selected, their normal assessment item became accessible as per normal. Only three students (1% of the enrolments) completely opted out of doing the concept tests.

During semester 1 in 2009 at UTAS, one mid-semester test and one exam were conducted. This enabled the results of those assessments to be compared with the corresponding evaluations in 2008.

Analysis

Analysis is based on data collected through institutional teaching and learning evaluation questionnaires and examination and test marks from semester 1 in 2008 and 2009. In this paper, we will report on first semester examination results for UTS and UTAS.

Results: Physics at UTS

The final exam in the Physics unit at UTS in 2008 and 2009 consisted of a number of sections. These sections were 'Kinetics', 'Forces', 'Momentum', 'Energy', 'Equilibrium', 'Thermal', 'Electricity', 'Oscillations and Waves' and 'Optics'. In 2008, this unit was taught entirely by the staff member participating in this project. However, in 2009, the same unit was taught by three different staff. Only the sections on 'Kinetics', 'Forces', 'Momentum', and 'Energy' were taught by the academic participating in this project. Consequently, only questions in these sections in both years' final exams are compared. The percentage of students who obtained full marks in each section is shown in Table 2.

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

Year	No. of students	Kinetics, % of full marks	Momentum, % of full marks	Forces, % of full marks	Energy, % of full marks
2008	388	79.77	69.3	32.2	63.0
2009	478	83.33	75.1	46.3	53.5
% change	23.2	4.5	8.4	43.8	-15.1
<i>p</i> -value		.57	.32	< .001	.07

The information in Table 2 informs us that despite a large increase in student number (23.2%), in 'Kinetics' in 2009 83.33% of the students achieved full marks as compared to only 79.77% of students in 2008. From the 'Momentum' section, the increase is 8.4%. In the 'Forces' section, the 2009 cohort of students outperformed the 2008 cohort by 43.8%. In the 'Energy' section, 2008 students outperformed the 2009 students by 15.1%. The Z test to compare two independent proportions was used and only the change for the 'Forces' section is statistically significant with $p < .001$. More importantly, student feedback results in semester 1 2009 showed that the rating of various teaching aspects for the participating staff member increased from an average rating of 3.62 out of 5 in 2008 to 4.05 in 2009 across all items. This is a good indication that many students had a better learning experience in 2009 than in 2008.

Results: Chemistry at UTAS

Table 3 summarises a comparison of the marks gained in KRA113 Chemistry 1A in each section of the final exams (taught by the same instructors except for Section C) in semester 1 in 2008 and 2009, respectively. Independent samples t-test showed that there is an increase in marks of 2.23 marks for section A (Structure and Bonding). Similarly for section B (Organic Chemistry), an increase of 4.76 marks was achieved in 2009 as compared to the marks in 2008. In section C (Thermodynamics), a decrease of -3.20 marks was achieved from 2008 to 2009. All three of these changes in marks are statistically significant. The data in Table 3 suggests that students in 2009 had improved in all areas of Chemistry 1 except in Thermodynamics (taught by different instructors in 2008 and 2009).

Table 3: Independent samples t-test comparing individual sections in the final exams conducted in semester 1 2008 and 2009, respectively

Test	YEAR	N	Mean	Std. Deviation	Sig. (2-tailed)	MEAN change
A total	2008	205	37.48	9.366	.018	2.23
	2009	205	39.71	9.696		
B total	2008	205	25.28	11.811	.000	4.76
	2009	205	30.04	12.691		
C total	2008	205	29.73	10.812	.004	-3.20
	2009	205	26.53	11.451		
Total	2008	205	92.49	28.848	.202	3.79
	2009	205	96.28	31.163		

Key: A: Structure and Bonding; B: Organic Chemistry; C: Thermodynamics.

Table 4 illustrates the distribution of the grades for the final exams in semesters 1, 2008 and 2009. First, the percentage of failures (FAIL) and passes (PP) have decreased by 7.8% and 3.4%, respectively; the percentage of credits (CR), and distinctions (DN) have increased by 7.3% and 5.8%, respectively, but the percentage of high distinctions (HD) dropped by 2%.

These figures suggest that teaching interventions implemented in this project achieved an improvement in student performance for almost all groups of students except the High Distinction group. Students in the lower end of the grade spectrum seem to have benefited most. This demonstrated gain is also confirmed by students' significant satisfaction with the formative feedback strategies implemented. These strategies have attracted an average rating of 3.80 out of 5 (strongly agree) on the feedback section of the UTAS Student Evaluation of Teaching and Learning surveys for the units. Students valued the understanding gained through the use of Votapedia questions (3.55), the help that the concept tests gave in answering the weekly assignments (3.70), and the extensive feedback available when an incorrect response was made in the concept tests (4.14).

Table 4: The distribution of grades of final exams in semester 1 2008 and semester 1 2009.

Year		Count	Grade					Total
			FAIL	PP	CR	DN	HD	
2008	Count		105 (51.2%)	59 (28.8%)	22 (10.7%)	10 (4.9%)	9 (4.4%)	205 (100%)
2009	Count		89 (43.4%)	52 (25.4%)	37 (18.0%)	22 (10.7%)	5 (2.4%)	205 (100%)

Note that 'FAIL' also includes all supplementary and deferred exam results. Numbers in parentheses indicate the percentage within the year.

Discussion

In each of the science disciplines under investigation, there is an enormous number of resources at the students' disposal. However, the question arises as to whether many students have made use of this array of resources in the past? The short answer is probably 'no' due to lack of time and energy. Consequently, students may choose what to concentrate on without any or much guidance. Even with the limited initial data contained in this paper from UTS and UTAS Physics and Chemistry subjects, it is apparent that, even with large cohorts, learning interventions such as those designed for this project can be successful. The data supports the use of Votapedia and online full feedback questions as useful support mechanisms. Through the design and implementation of the concept tests, this project has already created a framework for lecturers to provide students with more cognitively and pedagogically sound guidance with specific examples of what such guidance could look like in each of the disciplines.

Results reported in this paper show that even with large classes in Science, effective teaching strategies can be implemented and can be successful. An important aspect of this project was to develop strategies that could be implemented with a relatively small amount of initial effort and which were under the control of the lecturers concerned. Once implemented, it was found that the strategies and techniques discussed were easy to maintain and were readily adapted to new teaching experiences. Not only has this project successfully changed disciplinary lecturers' practice by letting them manage the strategies themselves and thus making the strategies sustainable, but it also resulted in significant improved student outcomes and satisfaction.

This paper also demonstrated the value and effectiveness of the peer-assisted teaching development approach. In this project we have found that coaching practice before lectures and tutorials in private between the educationalist and the lecturers was an essential element in developing the motivation for change and 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 concepts which students might not understand. This preparedness enhanced the delivery of the content using the new protocols.

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