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Can language focussed activities improve understanding of chemical language in non-traditional students?

Rees, S., Kind, V. & Newton, D.P.

Abstract

Students commonly find the language of chemistry challenging and a barrier to developing understanding. This study investigated developments in chemical language understanding by a group of non-traditional students over the duration of a one year pre-undergraduate (Foundation) course at a UK university. The chemistry course was designed to include a range of literacy based strategies to promote understanding including: word games, corpus linguistics, word roots and origins, and reading comprehension. Understanding of a range of chemical language was assessed with the development of a chemical language assessment (CLA) that was administered three times during the year. The CLA assessed understanding of scientific affixes, symbolic language, non-technical words, technical words, fundamental words and topic specific vocabulary. Results indicate that chemical language understanding improved over the duration of the study with moderate to large effect sizes. Students who scored low in the initial CLA (below 40%) improved but their scores remained lower than the rest of the students at the end of the year. The topic specific and technical sections scored low for all students at the start of the year and remained the lowest at the end of the year. Examples of symbolic and non-technical language remained problematic for some students at the end of the year. There was a correlation (r=0.53) between initial CLA score and final exam outcomes although some students with low initial CLA scores did perform well in the final exam. These findings are discussed in relation to the role of literacy based strategies in chemistry teaching.

Key words

Chemical language, literacy, non-traditional students, science education

Introduction

Societies are becoming increasingly technology advanced and more globally connected, highlighting the importance for developing scientific understanding (International Council for

Science [ICSU], 2011) and the need to make science education accessible to all students (NGSS Lead States, 2013). The language of science represents a significant barrier to engagement and development of understanding especially with the changing nature and diversity of the student population in language, culture and ability (Childs *et. al*, 2015). There are the challenges of subject specific vocabulary; whether this is specific technical terms, everyday words used in a scientific context or words with multiple meanings (Wellington and Osborne, 2001). This point can be simply illustrated by considering a word such as salt which has an everyday meaning defined as “A white crystalline substance which gives seawater its characteristic taste and is used for seasoning or preserving food” and a specific chemistry meaning defined as “Any chemical compound formed from the reaction of an acid with a base, with all or part of the hydrogen of the acid replaced by a metal or other cation” (Oxford University Press, 2018). In order to understand the meaning in chemistry there are a further eight scientific words to comprehend (chemical, compound, reaction, acid, base, hydrogen, metal, cation). Some of these may be familiar in everyday language (metal), specific to science (cation) or have multiple meanings (base). Furthermore, the language usage is imprecise and the meaning ambiguous. For example, what does “with all or part of the hydrogen of the acid replaced” really mean? To the non-specialist and novice chemistry student this could be interpreted as meaning part of the hydrogen itself being replaced. There is no reference to specific entities and what is being replaced such as atoms or ions. A clearer definition would be “a salt is a chemical compound formed from the reaction of an acid with a base. During the reaction, cations replace hydrogen ions of the acid to form a salt.” As subject specialists, it is always important to reflect on how those who are less knowledgeable and familiar with the subject will interpret what is written.

Words science teachers use have been shown to be inaccessible to students. Gardner (1971), for example, noted difficulties with everyday words such as consecutive, spontaneous, standard and stimulate used in scientific contexts. There have been a number of studies since then which have confirmed and expanded on these findings in a range of contexts. Cassels and Johnstone (1985) and Oyoo (2017) identified how students had greater difficulty understanding words in a scientific context and Pickersgill and Lock (1991) reported instances of students indicating opposite meanings to that which was intended or mistaking similar words such as contract and retract.

However, the language of science exists beyond the world of words alone and includes diagrams, equations and mathematical expressions (Lemke, 1998) as well as the language of formal representations of molecular structures referred to as a graphical or iconic language (Grosholz and Hoffmann, 2000). Markic and Childs (2016) coined the term

“Chemish” to encompass the multifaceted and broad nature of the language of chemistry and its impact on student learning.

Consequently, a number of authors (Markic & Childs 2016; Pyburn *et al*., 2013; Taber, 2015 and Wellington and Osborne, 2001) have argued for the importance of explicitly teaching language and developing language skills within chemistry teaching. For example, Brown and Concannon (2016) demonstrated the use of close reading strategies and their impact on student perceptions of learning scientific vocabulary. Students reported that their perception of vocabulary knowledge had increased post instruction and they believed the literacy strategies were important for developing science knowledge. In studies with English learners (ELs), improvements in achievement in science have been reported when direct language instruction is coupled with scientific enquiry (Garza et al., 2017; Lee, 2005). Language comprehension ability correlates strongly with student achievement on chemistry courses. Lewis and Lewis (2007), for example, analysed results obtained by 3000 college first year University general chemistry students in the United States. They established Scholastic Aptitude Test (SAT) scores as a meaningful predictor of students at risk of failing, based for example on a 0.527 correlation coefficient between verbal SAT and final exam scores. Pyburn *et al.* (2013) investigated over 1500 students enrolled on general chemistry courses at a research intensive university in north eastern United States. The students studied life science and engineering degrees with a chemistry requirement. Using chemistry exams set by the American Chemical Society (American Chemical Society, 2016) and comprehension ability measured by Scholastic Aptitude Test (SAT) Scores and the Gates MacGinitie reading test (Houghton Mifflin Harcourt, 2016), these authors demonstrated that students’ general language comprehension ability correlated significantly with performance in chemistry, with medium effect sizes for both measures of language comprehension. Furthermore, when controlling for prior knowledge, higher comprehension ability was found to partially compensate for lower chemistry prior knowledge. This provides evidence that future success is not determined by prior subject knowledge but recognises that students who have or develop good language comprehension skills can achieve well. However, as Song and Carheden (2014) recognise, these quantitative studies use a general measure of language comprehension rather than specific chemistry language comprehension.

This study describes the application of a specific chemistry language assessment (CLA) which investigates development in student understanding of chemical language over a one year period. The study focuses on the application of a range of language focused activities within the chemistry classroom with a cohort of non-traditional students (over the age of 21 and/or lacking usual qualifications for undergraduate entry) at a UK university.

Theoretical framework: vocabulary and knowledge construction in chemistry

Social constructivism

Constructivism proposes that individuals construct individual interpretations of their experiences and learners engage in a meaning making process to develop conceptions of knowledge (Applefield, Huber and Moallem, 2000). The term can be traced to Bruner (1966) with his description of discovery learning and “constructionist”, and Piaget (1977) who explained that knowledge proceeds from successive constructions. He suggested that as children learn more about their environment they become better adapted, a process he referred to as “equilibration” (Driver, 1988). In contrast to the Piagetian model of child development which is based on physical interaction with the environment, social constructivism emphasises language and discourse (Edwards and Mercer, 1987). Through social interaction learners refine their meanings and help others find meanings (Applefield, Huber and Moallem, 2000). This viewpoint is heavily influenced by Lev Vygotsky (1896 – 1934), a Russian developmental psychologist. He studied development of cognitive processes and roles played by social interaction and language. Vygotsky (1962) proposed language and thought combine to create a cognitive tool for human development. Language development and conceptual development are inextricably linked (Vygotsky, 1962) and difficulty with language causes difficulty with reasoning (Byrne, Johnstone and Pope, 1994) Students’ linguistic abilities are critical to development of internal understanding and external articulation.

In addition, the teacher has a central role as a language user (Glasersfeld, 2005) leading students to more complex conceptual understanding than could be achieved by students working alone. Vygotsky (1962) differentiated between “spontaneous” and “scientific” concepts. Spontaneous concepts emerge from a child’s reflection on everyday experience. Scientific (academic) concepts originate in the classroom activity and develop logically defined concepts. Vygotsky was interested in facilitating learning to enable a child to progress from spontaneous to scientific concepts. He argued scientific concepts do not come to learners ready-made, but work their way “down” whilst spontaneous concepts work their way “up”, meeting the scientific concept and allowing the learner to accept its logic (Fosnot and Perry, 1996). Vygotsky referred to the interface where a child’s spontaneous concepts meets the teacher's scientific concepts as the *zone of proximal development* (ZPD) defining it as the distance between the actual developmental level achieved independently and the level of potential development in collaboration with more capable peers (Vygotsky, 1978). Thus the teacher does not dispense knowledge but supports or "scaffolds" students progressing within their ZPDs; as new levels are attained scaffolding is altered accordingly.

Johnstone's triplet

Johnstone (1991, 2000) developed a view that chemistry learning occurs on three levels: macroscopic, that is what can be seen, touched and smelt; sub-microscopic, that is atoms, molecules, ions and structures; and symbolic meaning, representations of formulae, equations, mathematical expressions and graphs. Inspired by a geologist's diagram describing mineral composition, Johnstone arranged these levels at the apexes of an equilateral triangle to indicate equal, complementary significance. Teaching occurs "within" the triangle, under the assumption that all levels are equally well-understood. During chemistry learning, novice students must move between these three levels, often without notice or explanation. This introduces too much complexity for a novice chemist. A successful learner develops competence in and confidently inter-relates these three aspects. In order to achieve this, the learner must develop chemical linguistic confidence.

Taber (2013) revisited the triplet to address two confusions associated with Johnstone's model: firstly, the macroscopic level in terms of phenomenological and conceptual frameworks related to these phenomena; and secondly, the symbolic level and how this fits as a representational level with the macro and sub-microscopic levels. Taber argued that conceptual demand is high at the macroscopic apex as students deal with abstract notions relating to substances with unfamiliar names and classifications, for example, alkali metals, acids and reducing agents. He highlighted the role of specialised language in chemistry and how macroscopic concepts such as solution, element and reversible reaction or microscopic, including electron, orbital, hydrated copper ion need to be represented for a novice to think about them and communicate understanding with others. Taber (2013) argues the symbolic level should not be regarded as discrete in its own right but as a conduit for representation and communication of chemical concepts.

Language focused activities

Research in science education and second language learning has established a range of strategies to improve language comprehension (Wellington and Osborne, 2001). Teaching activities in this study were designed to develop understanding of key vocabulary by exploring the links between words and their origins (Sutton, 1992) and roots of words (Herron, 1996); develop learner confidence in using vocabulary orally and in their written work (Wellington and Osborne, 2001); promote meta-language discourse (Rincke, 2011) and apply data driven learning (DDL) to explore chemical language usage (Johns, 1991).

Corpora and Data driven learning

A corpus is a collection of authentic language which has been compiled for a particular purpose (Sinclair, 1991) and according to explicit design criteria (Flowerdew, 2012). Corpora are used in linguistic research to study patterns of language usage and for dictionary design. Their value to language learning is illustrated by Miller and Gildea's (1987) study of vocabulary teaching which showed that learning vocabulary from dictionary definitions accompanied by exemplar sentences is detached from mechanisms used for learning words in ordinary communication. Thus, as Brown, Collins & Duguid (1989) note, the context, or situation of a word within an utterance is crucial to ensure understanding. Studies in science education (e.g. Oyoo, 2017) have highlighted the importance of considering words in context to deduce meaning. Corpora which provide multiple examples of contextual usage of subject-specific language are potentially valuable as language-learning aids. The development of the unique Foundation Corpus (FOCUS) utilised in this study is described in Rees, Bruce & Bradley (2014) and Bruce, Coffer, Rees & Robson (2016).

The term "Data driven learning" DDL was applied by Johns (1991) to describe a learning situation in which "…*the language learner is also, essentially, a research worker whose learning needs to be driven by access to linguistic data – hence the term 'data-driven learning' to describe the approach.*" (p. 2). Through authentic language research, the students develop their language understanding. The corpus shortcuts language learning by providing repeated experiences of language instances. Mudraya (2006) utilized DDL with engineering students to develop understanding of scientific and non-technical vocabulary. In particular, she discussed different contextual uses of *solution,* and uses data to illustrate language structures observed in two contexts. The skilled use of DDL has potential for enhancing teaching and learning in chemistry for several reasons. Firstly, just like scientific content knowledge, it is evidence based. The learning is driven by the evidence revealed by searching the corpus. Secondly, like scientific enquiry, it is a "discovery learning" activity in which data are analysed to answer a specific question. Thirdly, it is a social constructivist activity in which students explore, develop and discuss their understanding based on evidence. Lastly, it can develop lexical and grammatical understanding without relying on linguistic meta-language to explain and discuss the observations. Meaning is developed via exemplification from data.

Research Questions

This study focuses on research questions investigating whether developments occur in students' knowledge and understanding of chemical language before and after implementation of language focused activities. The research questions are:

(1) Can language focused activities improve understanding of chemical language in non-traditional students?

(2) Does chemical language comprehension ability affect academic outcomes for non-traditional students?

Study context

The study was undertaken at a UK University with students enrolled on a full-time pre-undergraduate science foundation course for the duration of one academic year from October to June. The science foundation course recruits students without the required academic qualifications to gain entry directly to undergraduate degree programmes. These may be mature students (over 21 years old) or international students who are unable to study to the required level in their home country. Fifty two students progressing to biology, biomedical science, chemistry, medicine and pharmacy undergraduate degree programmes participated in this study.

Methods

This is a unique and longitudinal case study (Yin, 2003) of innovative teaching practice in a specific teaching and learning context. An experimental or quasi-experimental approach was considered but was not feasible for several reasons. It was not practically possible to have a randomly sampled control and experimental group that did or did not receive the language focused activities. It was also considered not ethically acceptable to expose some students to the activities whilst some students were not.

Chemical Language Assessment

To assess developments in understanding of different aspects of chemical language, a Chemical Language Assessment (CLA) was devised. The CLA contained six sections referred to as: affixes, fundamentals, word families, symbolic, non-technical and word choice. The affixes section required the students to match twenty affixes with their correct meaning e.g. Hydro – water. The fundamentals section assessed understanding of words such as atom, molecule and compound by requiring students to match the correct statement to a diagram e.g. atoms of an element with a picture containing only one type of circles. The word families section required students to write down as many words as they could think of associated with the topics of "acids and bases" and "kinetic theory and states of matter". The symbolic language section required students to state whether two symbolic representations were equivalent or not e.g. H_2O and OH_2. The non-technical section contained multiple choice questions requiring the students to select the correct meaning for a word with a different scientific meaning to its everyday usage e.g. weak. The word choice section provided students with an example sentence and asked them to suggest an alternative, more scientific word for the key word (highlighted in bold) e.g. Hydrochloric acid completely **splits** *(answer - dissociates)* into hydrogen and chloride ions in solution. The students undertook the CLA at the start of the course (October), at the end of the first term (December) and at the end of the course (May).

Teaching schedule

A detailed breakdown of the foundation chemistry teaching schedule including the language focused teaching activities with relevant CLA language highlighted is available in supplementary materials. The first term, October to December, commences with topics such as atomic structure, The Periodic Table and chemical bonding and progresses to introducing rates of reaction, equilibria and organic chemistry. The second term from January to May contains organic chemistry as well as electrochemistry, equilibrium constants and thermodynamics.

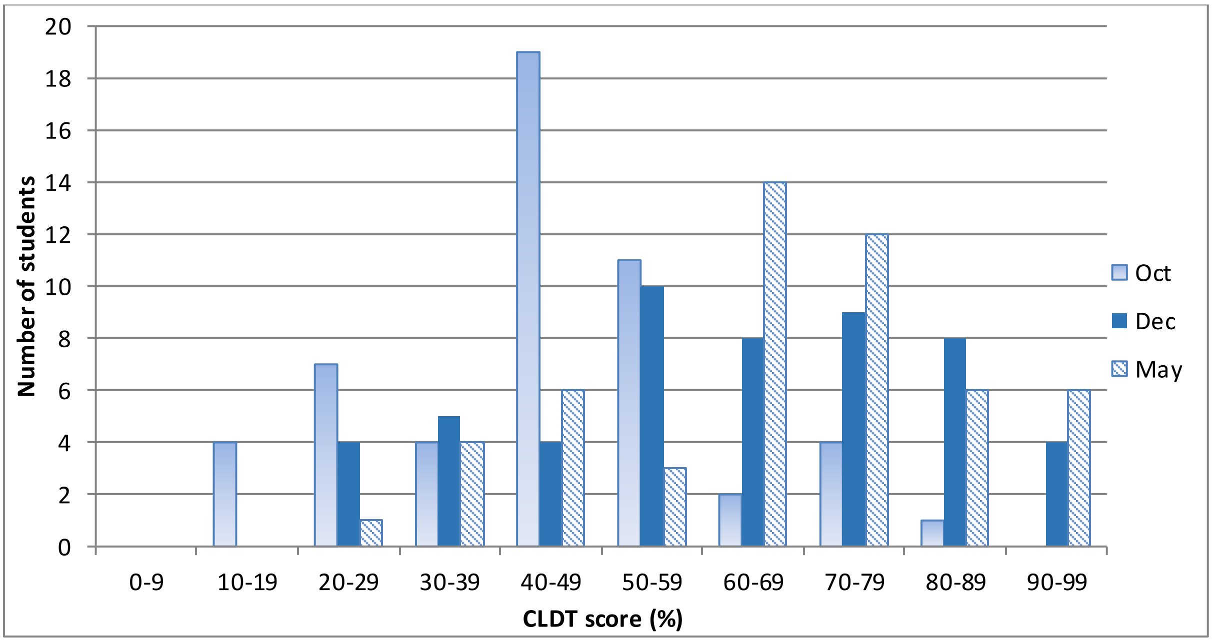
Results

For reporting, the data was divided into two sub-groups determined by baseline CLA data (Figure 1). The purpose of establishing these two sub-groups for analysis was to track the progress of students with the weakest language although all students received the same teaching activities. The threshold to divide the two sub-groups was set at a score of 40% in the October CLA. Fifteen students (29%) scored below 40%. This group are judged to demonstrate significant weaknesses in their chemical language understanding. This sub-group is referred to as the "Red" sub-group and have potential for the most substantial changes in chemical language use. Thirty seven students (71%) scored 40% or more and are referred to as the "Green" sub-group. Background data for the red and green sub-groups are reported in Table 1.

Sub-group	Red	Green	Total
Locus of previous education			
UK	11 (26)	31 (74)	42 (81)
Europe	0	2 (100)	2 (4)
Middle East	2 (75)	1 (25)	3 (6)
Asia	2 (50)	2 (50)	4 (7)
Africa	0	1 (100)	1 (2)
Total	15 (29)	37 (71)	52
Background*			
Work	9 (29)	22 (71)	31 (60)
Family	2 (25)	6 (75)	8 (15)
Direct from education	4 (31)	9 (69)	13 (25)
Gender			
Male	10 (29)	24 (71)	34 (65)
Female	5 (28)	13 (72)	18 (35)
Age			
<21	3 (30)	7 (70)	10 (19)
21-25	7 (30)	16 (70)	23 (44)
26-30	3 (23)	10 (77)	13 (25)
31+	2 (33)	4 (67)	6 (12)
Mean age	24.3	24.9	24.8
Standard deviation	4.6	4.1	4.4
Planned degree route			
Biological/Biomedical sciences	7 (39)	11 (61)	18 (35)
Chemistry	1 (25)	3 (75)	4 (8)

Earth sciences	3 (43)	4 (57)	7 (13)
Medicine	2 (18)	9 (82)	11 (21)
Pharmacy	2 (17)	10 (83)	12 (23)

Table 1 Red and Green sub-group background data



n = 52

Figure 1 CLA scores for October, December and May

The mean scores for the two sub-groups were statistically significantly different across the three test dates (Table 2). The Red sub-group scores are consistently lower than those of the Green sub-group.

CLA date	Red sub-group (n=15)		Green sub-group (n=37)		t	p
	Mean	sd	Mean	sd		
October	24.3	10.1	52.3	11.7	8.53	<0.001
December	42.9	13.5	71.5	7.5	6.74	<0.001
May	52.7	14.1	73.5	13.3	4.75	<0.001

s.d. = standard deviation t = two tailed t-test p = probability

Table 2 CLA Statistical data for the Red and Green sub-groups

There was a statistically significant difference ($t = 5.44$, $p<0.001$) between results for October (mean score = 44.2, sd = 16.6) and December (mean score = 63.3, s.d. = 19.0). Mean scores increased much less from December to May (mean = 67.5, sd = 17.1) and the difference is not statistically significant ($t = 1.21$, $p>0.1$). This may reflect the teaching sequence where content relating to CLA sections such as Fundamentals, Symbolics, Acids and Kinetic theory are taught in the first term. Reinforcement occurs from January to May. Therefore, students made larger gains in understanding from October to December which are consolidated later.

The Red sub-group showed a large effect size from October to May (Cohen's d = 2.4). However, this effect is primarily accounted for by October to December (d = 1.62) with a moderate effect size from December to May (0.67). The Green sub-group showed a moderately large effect size from October to May (d = 1.65). This sub-group shows a similar pattern to the Red sub-group with a larger effect size for October to December (d = 1.52) but a small effect size from December to May (d = 0.15).

Analysis of CLA language component scores

Table 3 reports mean May CLA section scores by sub-group. Figures 2 and 3 show the change in mean scores by section for the Red and Green sub-groups. Six CLA sections, *Acid words, Affixes, Fundamentals, Non-technical, Symbolic* and *Word choice* were statistically significantly different in May. Only one section, *Kinetic words,* was not (Table 3).

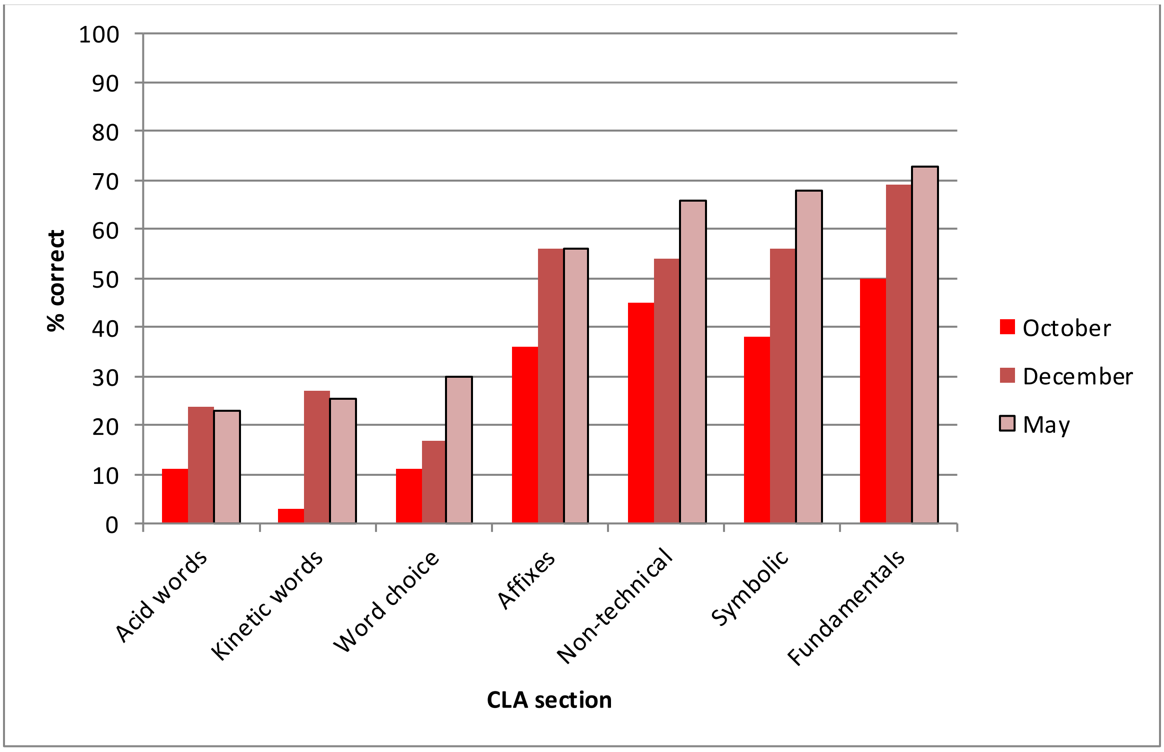
The *Acid words*, *Kinetic words* and *Word choice* sections were the lowest scoring for both sub-groups in May. The Red sub-group scored 30% or below and the Green sub-group scored below 60% in these three sections. Despite experiencing the relevant vocabulary during the year, many students remained unfamiliar with the words at the end of the year. From January to May, the Red sub-group showed an increase from 17% to 30% for the *Word choice* section but *Acid words* and *Kinetic words* showed a small decrease (not statistically significant). This suggests that the teaching activities from January to May had little impact on the students' ability to recall relevant vocabulary for these two topics.

	Red sub-group (n=15)		Green sub-group (n=37)			
Section	Mean score (%)	s.d.	Mean score (%)	s.d.	t	p

Acid words	23	17.2	59	28.1	3.90	<0.001
Affixes	56	27.3	84	20.4	3.49	<0.05
Fundamentals	73	38.8	98	17.4	2.21	<0.05
Non-technical	66	24.6	95	12.1	2.55	<0.05
Word choice	30	17.6	59	19.5	2.61	<0.05
Symbolic	68	27.0	94	18.2	2.31	<0.05
Kinetic words	26	16.9	44	18.4	1.90	>0.05

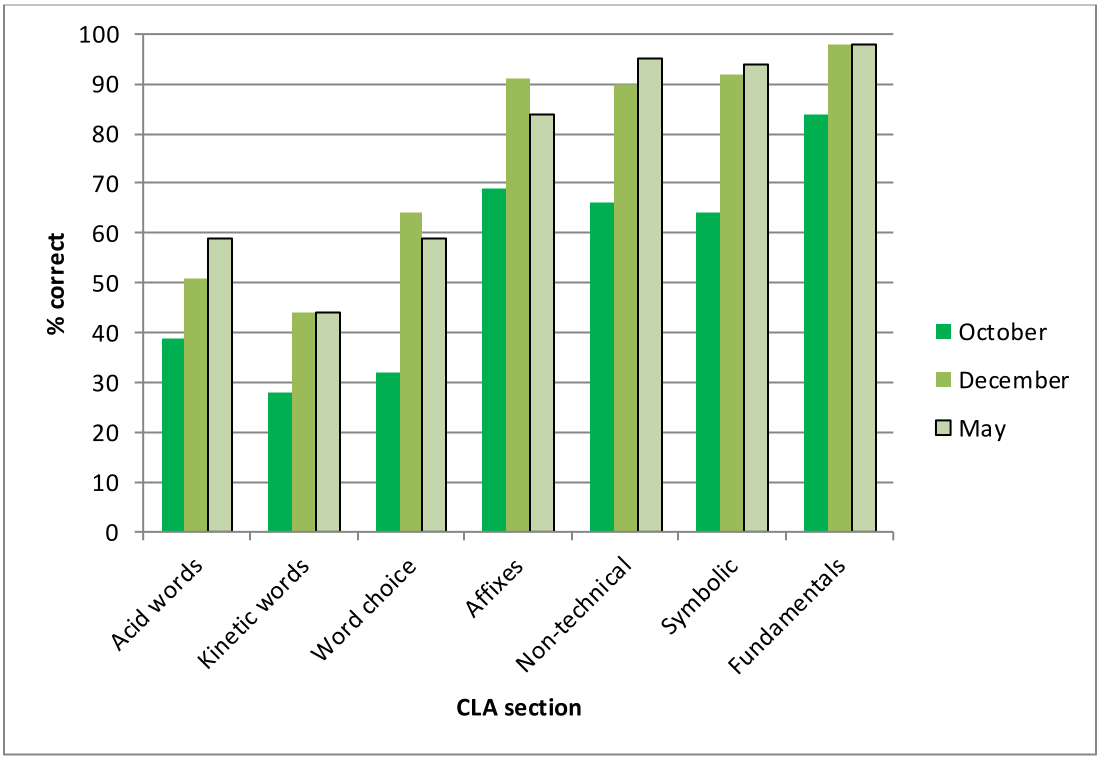
s.d. = standard deviation   t= Two tailed t-test   p= probability
Grey shading indicates statistically significantly different data.

Table 3 Statistical data of May CLA results for Green and Red sub-groups



n=15

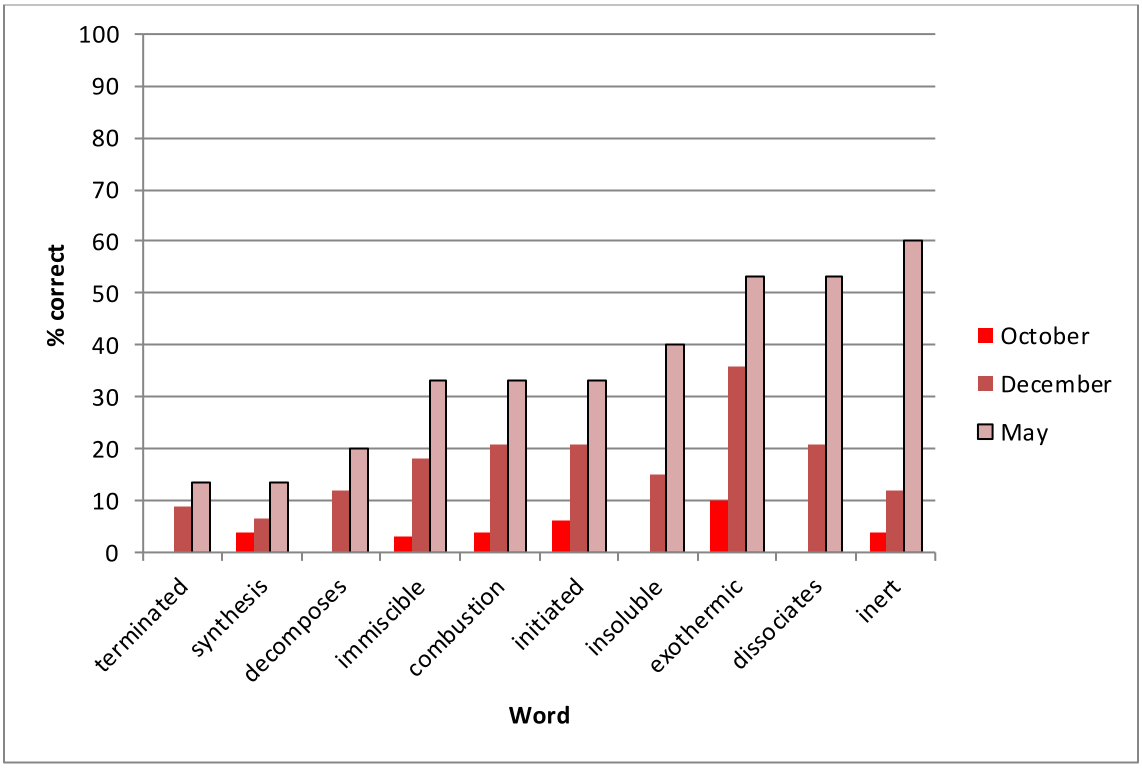
Figure 2 Red sub-group CLA section scores from October to May



n=37

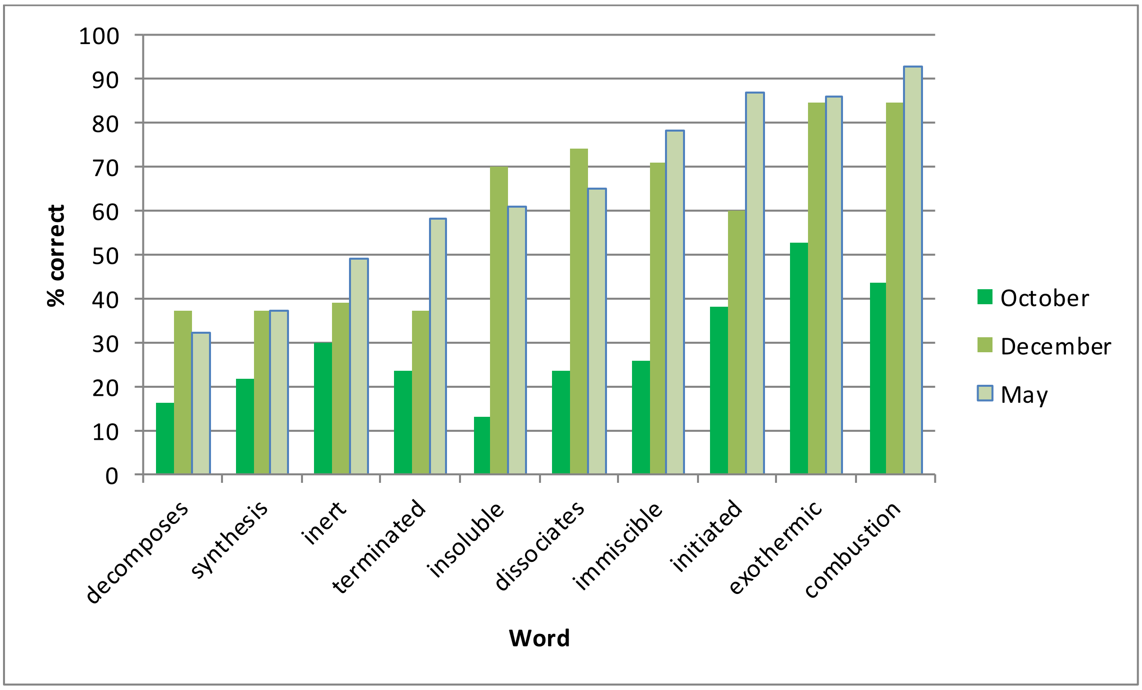
Figure 3 Green sub-group CLA section scores from October to May

Figures 4 and 5 show the proportions of students giving correct responses to each of the *Word choice* questions for Red and Green sub-groups during the year. The data indicates continued problematic knowledge of these scientific words at the end of the year. In May, Exothermic and Dissociates were correctly used by over 50% of Red and Green sub-group students. Inert was correctly answered by more Red sub-group than Green sub-group students. This suggests that the teaching activities had led to a majority of the Red sub-group students developing an understanding of these words during Year 0. Exothermic is regularly encountered in weeks one, five, eight, nine and sixteen. Dissociate is encountered in weeks six and nineteen and is a key word for the Weak teaching activity in week 9. However, over 40% of AY23 did not use the word correctly in the May CLA. Combustion is also a regularly encountered word in weeks one, ten, eleven and fourteen but over 65% of Red sub-group students did not answer this question correctly in May. Terminated, Synthesis and Decomposes were correctly used by 20% or less of Red sub-group students. Terminated and Decomposes are not used explicitly during the teaching whilst Synthesis is used during the organic chemistry section of the course from weeks eleven to fifteen. Previous studies (Oyoo, 2017) have particularly focused on the challenges of non-technical words and words with dual meaning but these results suggest that understanding of these technical words can also be limited for some students.



n=15

Figure 4 Red sub-group percentage correct responses to the CLA *Word choice* section

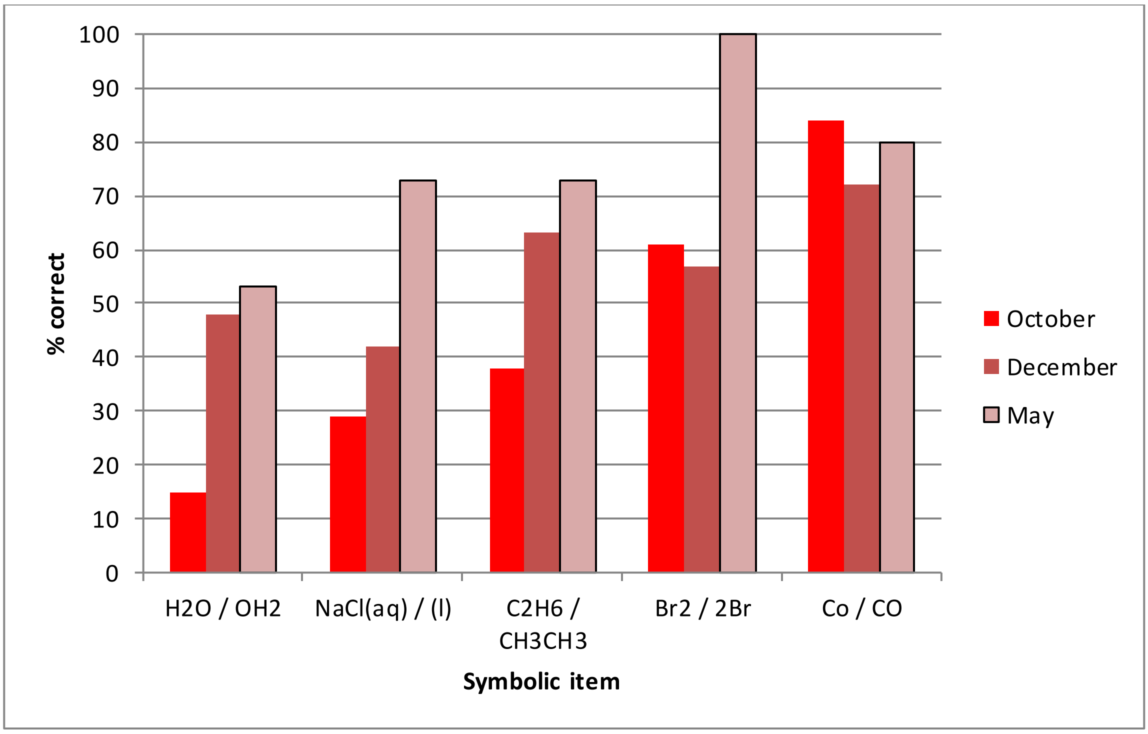


n=37

Figure 5 Green sub-group percentage correct responses to the CLA *Word choice* section

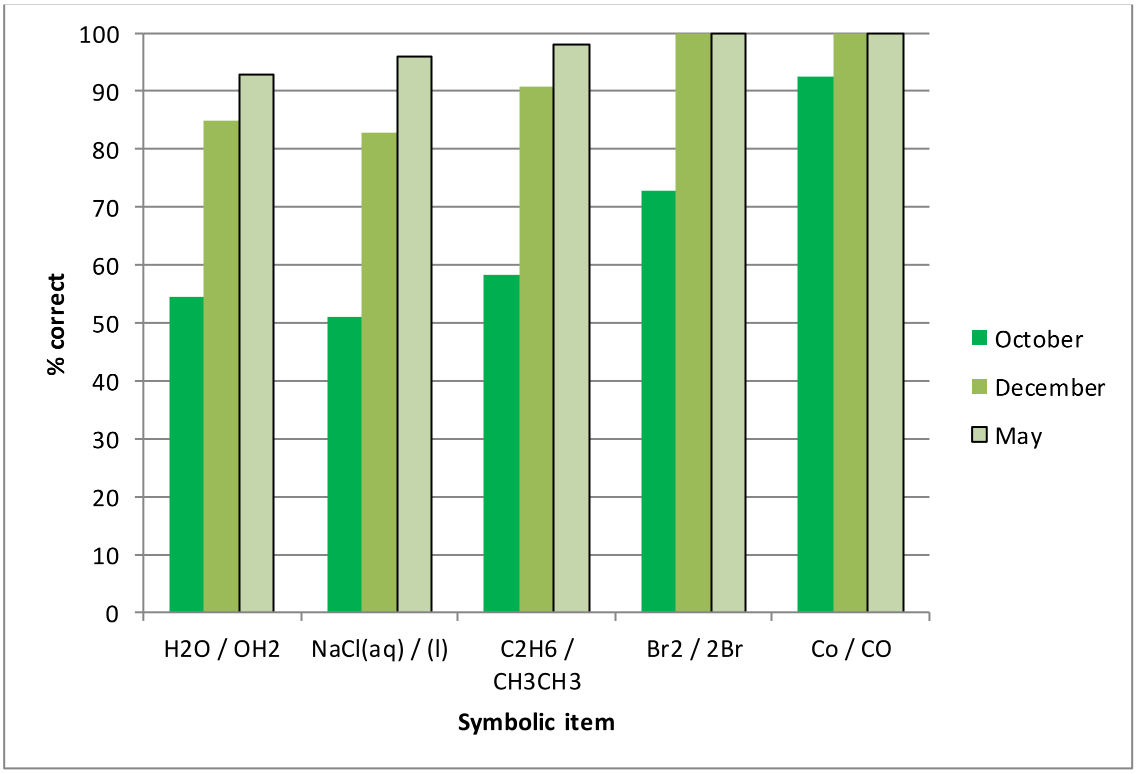
The Affixes, Non-technical, Symbolic and Fundamentals sections were the highest scoring sections in October and achieved the highest scores in May (Figures 2 and 3). The Red sub-group scored over 55% correct in these sections and the Green sub-group scored over 75% correct. There is a general pattern across the different sections showing an initial increase from October to December followed by a plateau in May. Understanding of affixes was emphasised throughout and was the focus of the teaching activity on week 2. However, the Red sub-group scored 56% correct in May indicating that the students did not know the meaning of many affixes presented in the CLA. The Red sub-group showed improvement in the Fundamentals section from October to December and smaller increase in May. This suggests that students with limited understanding of these terms in December continued to have difficulty in May.

The Symbolic section scores for the Red sub-group increased from 37% in October to 68% by May. The H_2O/OH_2 and NaCl(aq)/(l) items posed the greatest difficulty in October but there was improvement by May (Figure 6 and 7). In May, 73% of Red sub-group students answered NaCl(aq)/(l) correctly compared to 29% in October, indicating improved understanding of state symbols and/or the difference between liquids and solutions. However, 47% of Red sub-group students answered the H_2O/OH_2 item incorrectly in May compared to 7% of Green sub-group students. The C_2H_6/CH_3CH_3 item also tests understanding of sequences in chemical formulae. Over 70% of Red sub-group students answered this question correctly, although they did perform statistically significantly worse than the Green sub-group ($\chi^2 = 7.2$, $0.01>p>0.005$). This suggests that some Red sub-group students continue to find interpreting chemical formulae problematic at the end of the Foundation year. Difficulties in understanding formula subscripts have been reported by De Jong and Taber (2014).



n=15

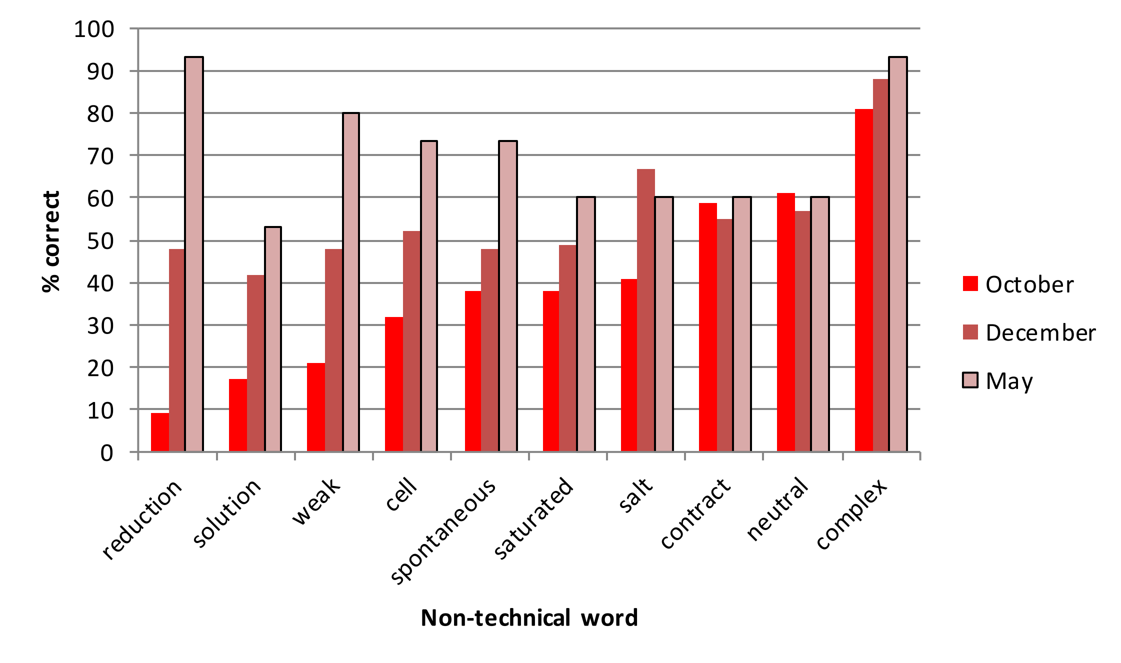
Figure 6 Red sub-group percentage correct responses to the CLA *Symbolic* section



n=37

Figure 7 Green sub-group percentage correct responses to the CLA Symbolic section

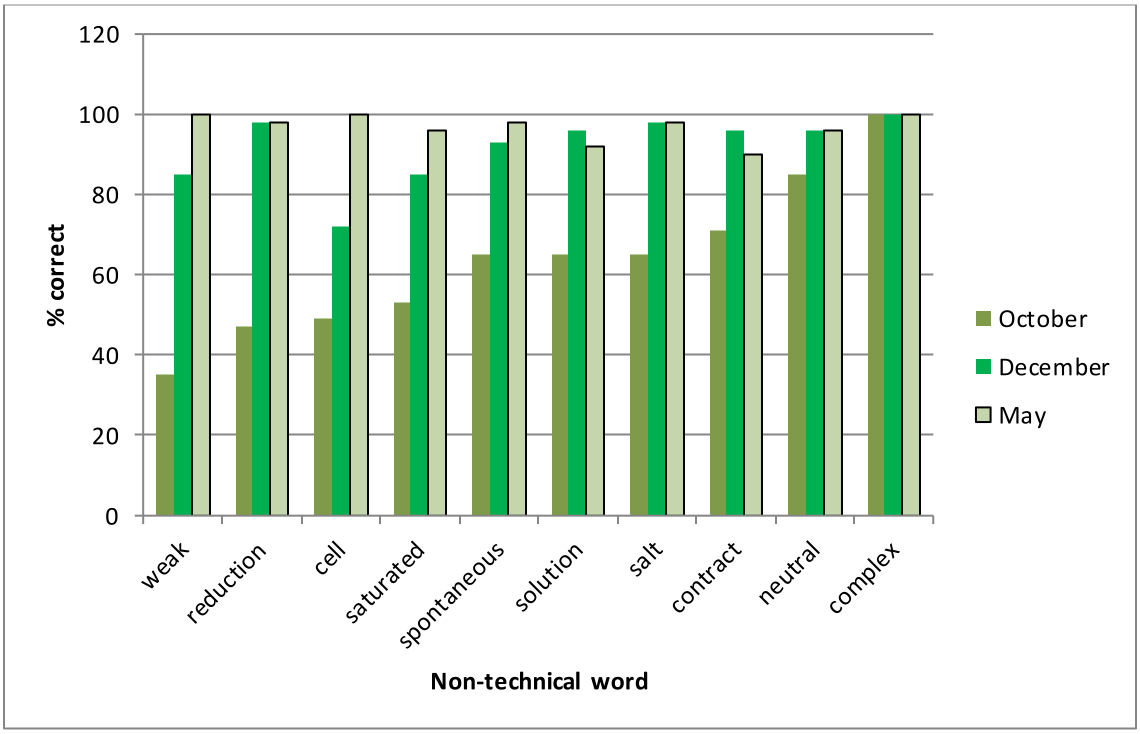
In the Non-technical section, the results suggest three different types of words can be identified for the Red sub-group (Figure 8).



n=15

Figure 8 Red sub-group percentage correct responses to the CLA *Non-technical* word section

Firstly, one word, *Complex*, was understood well in October and in May. This word did not present difficulty to the students, demonstrating consistency in response on the three test dates. Secondly, The words Solution, Cell, Spontaneous, Reduction and Weak some were understood poorly in October with scores between 5% and 40% correct but showed improved understanding in May to between 50% and 95% correct. This suggests the teaching activities had developed students' understandings of these words. The meanings of Solution, Cell, Reduction and Weak were taught explicitly. The meaning of Spontaneous was not explicitly taught. The final group of words, Salt, Contract, Saturated and Neutral had correct scores of between 35% and 60% in October but showed smaller or no improvements in May. This suggests the teaching activities had minimal impact on students' understandings of these words. The meaning of Salt and Saturated was taught explicitly in weeks 6 and 15 respectively. The meaning of Contract was not taught explicitly. Figure 9 shows the Green sub-group reported similar trends to the Red sub-group.



n=37

Figure 9 Green sub-group percentage correct responses to the CLA Non-technical word section during the Foundation year

However, at least 85% of Green sub-group students identified the correct meanings of all words. Complex was correctly understood by all Green sub-group students. Scores for Spontaneous, Cell, Weak, and Reduction showed significant improvements in May. Saturated and Salt also showed improvement suggesting the Green sub-group had improved understanding of more words than the Red sub-group. Similarly to the Red sub-group, scores for Contract and Neutral showed less improvement from October to May. Table 4 shows the Red sub-group continued to score statistically significantly less for all non-technical words in May apart from Complex and Reduction.

Non-technical word	Correct score (%) Green sub-group (n=37)	Red sub-group (n=15)	χ^2	p
Salt	98	60	12.7	<0.001
Saturated	96	60	12.7	<0.001
Cell	100	73	11.7	<0.001
Solution	92	53	11.6	<0.001
Neutral	96	60	11.4	<0.001
Weak	100	80	7.9	0.01>p>0.005
Spontaneous	98	73	7.3	0.005>p>0.001
Contract	90	60	5.2	0.05>p>0.01
Complex	100	93	2.3	>0.1
Reduction	98	93	1.0	>0.1

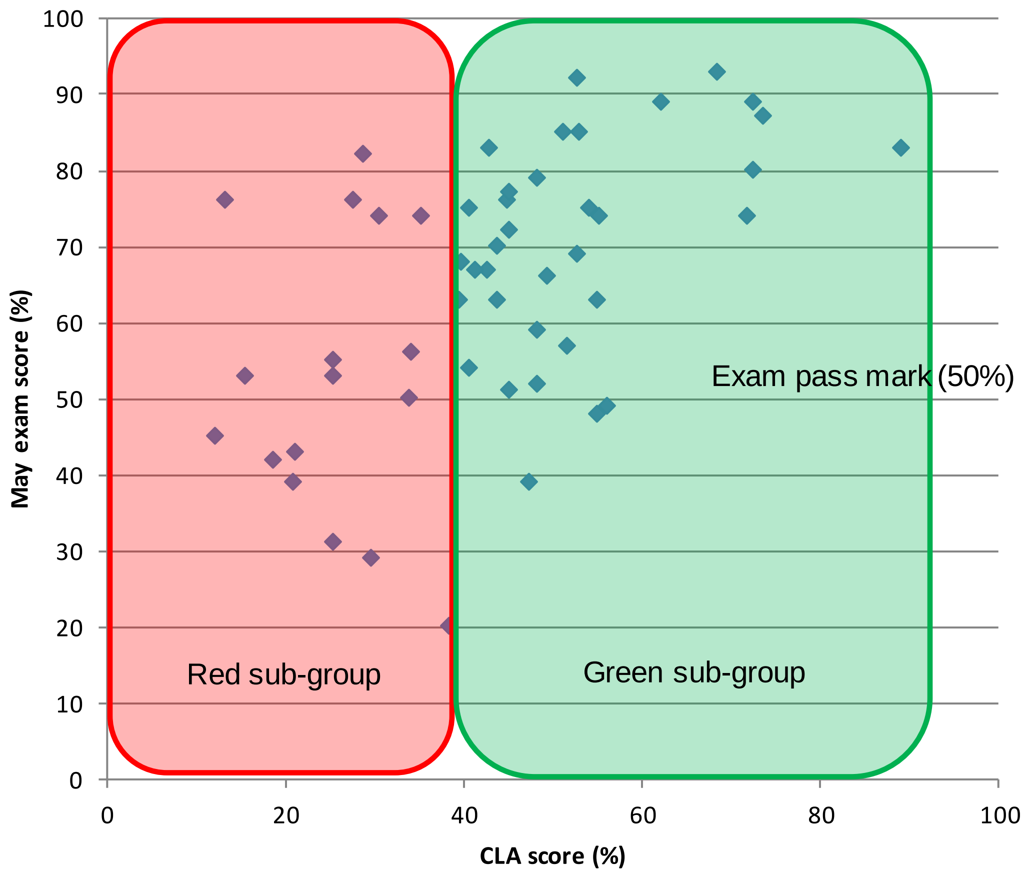
χ^2 = Chi squared p = probability

Grey rows highlight words with statistically significant scores.

Table 4 Statistical data of the May CLA Non-technical section for Green and Red sub-groups

Comparison of CLA and chemistry exam scores

Figure 10 shows May chemistry exam score against October CLA score. The correlation coefficient (r) is 0.53 indicating that the October CLA score correlates with the final May exam score. Seven out of fifteen (44%) Red sub-group students failed the May exam with scores of less than 50%. Three out of thirty seven students (8%) of Green sub-group students failed the May exam. These results indicate that a student who scored poorly in the October CLA was more likely to fail the final examination than those scoring highly in the October CLA. Five students in the Red sub-group scored above 70% in the May exam indicating that they had responded to the teaching activities and made substantial progress in chemical language understanding. Four students who scored between 50% and 60% indicate they had made sufficient progress to pass the May exam. This suggests some students responded to the teaching activities whilst others did not, and other factors influenced success.



n = 52   r = 0.53

Figure 10 Scatter plot showing May exam scores against October CLA scores

Discussion

All students showed weakness in lexical-based word categories at the start of the course and this remained the case at the end. Figures 2 and 3 show that the lowest scores in the CLA in October were recorded in acid words, kinetic words and word choice sections for all students and, whilst these scores improved, they remained the lowest scoring sections in May.

The acid and kinetic word sections were designed in a format in which students had five minutes to suggest up to 15 topic-related words. In general, students struggled to recall a substantial number of topic related words. These sections may have exposed general weakness in that, even if students scored well in tests, their awareness and knowledge of topic related vocabulary was limited.

Similarly, low scores in the word choice section indicate limited awareness of scientific alternatives to everyday examples used. The teaching activities had limited impact on this area with scores remaining low in May.

Cassels and Johnstone (1985) highlight difficulties associated with non-technical language. In this study, the ability to track understanding over time demonstrated how understanding of non-technical language improved. Figure 2 shows that the October CLA score for this section was low with an average of 42% for the Red sub-group. The words solution, reduction and weak had very low scores (Figure 8). However, during the year, the score substantially improved with the Red sub-group scoring 66% correct in May. Solution had the lowest score of 53% but weak and reduction had high scores of 80 and 93% respectively. Weak and reduction received explicit and repeated use in different contexts, a strategy highlighted as important by Lemke (1990). Cassels and Johnstone (1985) investigated understanding of these words across year groups, but this study tracks changes in understanding of specific students over time. Understanding of these words improves with repeated exposure.

Red sub-group students demonstrate problematic understanding of fundamental terms such as atom, molecule and compound, evidenced by an average score for the fundamentals section of the CLDT in October of 55% correct. Some students performed very poorly, indicated by the high standard deviation of 38.8 (Table 3). Limited understanding of these fundamental and ubiquitous words is a concern so their meaning was addressed explicitly early in the teaching sequence. Whilst understanding of these words by Red sub-group students improved to 70% correct in May (sd = 39.1), this remained significantly less than scores obtained by Green sub-group. This indicates that some students remained insecure in their understanding of these terms.

De Jong and Taber (2014) reported student difficulties in interpreting formula subscripts and this is supported in these results. This sub-group recorded a low score in the symbolic language section in October. The section remained problematic for some students (Figure 6). In particular, nearly 50% of Red sub-group students did not consider H_2O and OH_2 to be equivalent at the end of the year. This response could indicate continued lack of understanding of chemical formulae, such that when formulae are presented in an unfamiliar context the meaning is unclear.

CLA results indicate a correlation with achievement in the end of course examination. Students with low initial CLA scores were less likely to be successful (Figure 10). Some of these students significantly improved whilst others did not. Despite the explicit language focused activities, some students continued to show weaknesses in different areas of chemical language at the end of the course which impacted on their academic achievement.

Conclusion

In relation to Research Question 1, this paper has demonstrated how language focused activities can be successfully incorporated into chemistry teaching in the context of a diverse group of non-traditional students. The benefit of these strategies is illustrated by this quote from one of the students progressing to medicine:

"I will be honest and say I was a little sceptical about the benefits of the linguistics project to myself, which highlights my lack of knowledge now! However, as this first year in medicine has progressed and I'm being exposed to increasing medical literature and new concepts. In subtly but significant ways, the linguistics work has made it far easier for me to rapidly understand and grasp new material. I can now fully appreciate the barrier that language can create in the comprehension of new material. The medical literature itself may not be difficult, but the literature language can be very inhibiting and restrictive. Your linguistic and comprehension work is now one of the most important benefits of my foundation year!"

The use of these literacy strategies is important for chemistry to successfully engage with an increasingly diverse student population. The CLA enabled the tracking of student understanding of chemical language over a one year academic course. Those students with poor understanding of chemical language at the start of the course (Red sub-group) showed improvements over the year in some areas but not in others. This indicates how, despite the specifically designed activities, understanding of chemical language can remain problematic.

With reference to Research Question 2, the results indicate a correlation between initial CLA scores and final chemistry exam scores ($r= 0.53$). This suggests that chemical language comprehension ability does affect academic outcomes for non-traditional students and emphasises the importance of focussing pedagogy to address these issues.

Limitations

The CLA is limited in the extent to which it probes "real" understanding of chemical language and the areas it assessed. However, this study intended to produce a test that could be used readily in a teaching situation.

Whilst large effect sizes for this study were obtained it is not possible to attribute this solely to the teaching activities because the experimental design could not incorporate a control group not exposed to the intervention. The study was limited to the experience of non-traditional students in one institution and may not be generalised.

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