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A case study exploring developments in non-traditional potential undergraduates' understandings of chemical language

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Abstract

This study investigates learning outcomes achieved by Foundation programme (Year 0) students preparing over one academic year to progress to a three year Bachelor's degree in biological science, chemistry, computer science, earth sciences, medicine, pharmacy or physics. The thesis reports the development of a range of teaching activities focussing on students' chemical language. Knowledge of chemical language is vital to developing student understanding but is an under-researched area.

The teaching activities comprise a range of language focused strategies. A unique corpus of student work (Foundation Corpus or FOCUS) from Year 0 to PhD level is developed that is used in a range of corpus linguistics based teaching activities. Other activities include word games, mini-whiteboards, modelling and directed activities related to text.

Quantitative data were collected from eighty six students over two years by the development of a unique chemical language diagnostic test (CLDT). The test assesses understanding of a range of chemical language: scientific affixes, fundamental words (such as atom or molecule), acid and bases, kinetic theory, non-technical words, symbolic language and technical words. Qualitative and quantitative data were collected from six students over four years by semi-structured interviews. The data consists of explanations of chemical scenarios and is analysed for students' usage of chemical language. Twenty students undertake an eye tracker task that provides quantitative data on students' eye movements when reading text.

Outcomes indicate strong correlations between initial CLDT score and chemistry examination score at the end of Year 0. This suggests that students scoring poorly on chemical language face more challenges to reach the required grade to pass Year 0 than those with better linguistic skills. Evidence is provided for the existence of "chemical interlanguage" and discusses linguistic demand in multiple dimensions. The study reinforces the need to engage positively with chemical language acquisition, offering strategies for developing this and methods for its assessment.

Declaration

The copyright of this thesis rests with the author other than where explicitly stated. No quotation from it should be published in any format, including electronic and the Internet, without the author's prior written consent. All information derived from this thesis must be acknowledged appropriately.

This thesis results entirely from my own work and has not been offered previously for any other degree or diploma.

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Financial support for analysis of concordance tools and development of FOCUS was obtained from the Higher Education Academy and the UK Council for International Student Affairs.

This research, however, would not have been possible had it not been for the inspiring students of the Foundation Centre. I will always remain grateful for their willingness to participate in the study.

List of Abbreviations

APU	Assessment of Performance Unit
AY	Academic Year
BERA	British Education Research Association
CCL	Correct Chemical Language
CLDT	Chemical Language Diagnostic Test
DART	Directed Activity Related to Text
DDL	Data Driven Learning
DES	Department of Education and Science
FOCUS	Foundation Corpus
GCSE	General Certificate of Secondary Education
HE	Higher Education
ICL	Incorrect Chemical Language
NCI	Neutral Chemical Interlangauge
NGSS	Next Generation Science Standards
OECD	Organisation of Economic Cooperation and Development
KWIC	Keyword in context
PCI	Productive Chemical Interlanguage
PISA	Programme for Individual Student Assessment
SAT	Scholastic Aptitude Test
STEM	Science Technology Engineering and Mathematics
TEF	Teaching Excellence Framework
UCI	Unproductive Chemical Interlanguage
UK	United Kingdom
ZPD	Zone of Proximal Development

Glossary of Terms

A-level	The standard school leavers' qualification suitable for entry to Higher Education in the UK.
Backsliding	A form of interlanguage where a learner returns to using more basic language.
Concordancer	The software programme to search a corpus.
Corpus	A collection of authentic language which has been compiled for a specific purpose (Sinclair, 1991).
Data driven learning	Learning undertaken by researching language data.
Dual meaning vocabulary	Scientific words that have different meaning in an "everyday" context.
Eye tracking	An infra-red system that tracks eye movements around a computer screen.
Flipped learning	Direct instruction delivered prior to a group learning session via resources such as screencasts to provide active learning opportunities during group learning.
Interlanguage	A transitionary language with systematic rules (Selinker, 1972).
Keyword in context	A concordancer displays the keyword within the middle of a short section of text.
Non-technical words	Scientific words that are also used in an everyday context and may have different meanings.

Non-traditional students	Students over the age of 21 or do not have the typical qualifications for entry in to Higher Education in the UK.
Potential undergraduates	Year 0 students.
Regressions	A backward eye movement to read text previously encountered.
Saccades	Rapid movements that move the eye from one place to the next when reading.
Scientific words	Words specifically developed for science.
Social constructivism	Learners engage in an interactive meaning making process to develop conceptions of knowledge (Applefield, Huber and Moallem, 2000).
Screencasts	Narrated Powerpoint® recordings.
Year 0	The pre-undergraduate foundation year.
Year 1	First year of the undergraduate degree programme.
Word attack skills	The ability to determine the meaning of new words based on knowledge of word roots (Herron, 1996).
Zone of proximal development	A term developed by Vygotsky (1978) to represent the difference between students' actual developmental level demonstrated by independent study and the level achievable through collaboration with capable peers.

Chapter 1

Introduction

Teaching and learning in Higher Education (HE) is in a state of transition in the UK. The raising of student fees and the development of the Teaching Excellence Framework[1] (Department of Business, Innovation and Skills, 2015) has stimulated intense scrutiny on teaching and learning in HE. Within the UK chemistry education community, the increasing emphasis on teaching and learning is evidenced by universities appointing Professors of Chemistry Education with the aim of driving innovation and excellence within their institutions. Johnson (2015) described the aims for the Teaching and Excellence Framework (TEF) as:

> *" - to ensure all students receive an excellent teaching experience that encourages original thinking, drives up engagement and prepares them for the world of work;*
>
> *- to build a culture where teaching has equal status with research, with great teachers enjoying the same professional recognition and opportunities for career and pay progression as great researchers;*
>
> *- to recognise those institutions that do the most to welcome students from a range of backgrounds and support their retention and progression to further study or a graduate job."* (no page number available)

This study is applicable to all three of these aims. Firstly, it contributes to ensuring *all* students receive an excellent teaching experience. Ideas and strategies explored in this thesis have the potential to contribute towards increasing comprehension and accessibility of chemistry to HE students. The thesis operates from the perspective that learning chemistry shares similarities with learning a second language, therefore arguing for greater linguistic awareness in chemistry teaching. Secondly, it demonstrates how pedagogical research can be undertaken by a full time teaching

[1] The Teaching Excellence Framework (TEF) is a UK government initiative to identify and incentivise high quality teaching in Higher Education.

fellow within a supportive workplace setting. This research benefits students in terms of the quality of their learning experience by deepening their lecturer's understanding of pedagogical theory. Lastly, the study is situated in the Foundation Centre, an academic department within a prestigious, research intensive university in the North East of England. The Foundation Centre contributes to widening participation by preparing potential undergraduates from non-traditional backgrounds[2] for undergraduate degrees. The centre contributes to diversifying the student body and has been cited as an example of good practice to increase social mobility in UK Government reports (Milburn, 2012). Strategies detailed in this thesis help to create a learning environment in which students, who traditionally may have not engaged with chemistry, have an opportunity to develop their understanding.

Joining university can be an exciting but also daunting time for potential undergraduates. Many experience fundamental change by returning to education after significant periods of time in employment or as carers. The Foundation Centre operates to acculturate these students to university and enable them to be successful in their degree level studies.

In the UK, insufficient students choose to study science, engineering, technology and mathematics (STEM) subjects and it is a skills shortage area (BP, 2016; Johnson, 2015). The perspectives and strategies employed in the study are designed to suggest how chemistry educators can expand their skills by incorporating language focussed activities. It is argued that this improves engagement, accessibility and understanding. The Foundation Centre cohort is a diverse mix of UK and international students. The international students have not had an opportunity to study for a qualification suitable for direct university entry. Therefore, this study is also of interest to those interested in improving the experience of international students studying chemistry and other sciences. UK universities must continue to develop the teaching and learning experience to ensure students achieve well. The thesis aims to demonstrate how developing their linguistic knowledge can benefit of international students.
This supports adoption of constructivist based modes of delivery such as "flipped learning" (Seery, 2015; Chapter 2, Section 2.8, p. 65). Flipped learning involves "front

[2] Students from non-traditional backgrounds are defined as over 21 years old or lacking the usual formal qualifications for university entry.

loading" of content by providing materials such as videos for students to access prior to a class. This then creates space and opportunity for interactive full class sessions which encourage the students the actively participate. The lecturer requires good linguistic awareness to design effective pre-class materials and class activities.

1.1 The language dimension of chemistry

The significance of the language my students and I use when developing understanding of chemistry has been very apparent. Students can become confused and disengaged when new concepts are introduced that require understanding of specialist vocabulary. Equally, they take satisfaction and gain confidence when "*talking like a scientist*", participating in discussions and producing work that is rich in chemical language. I have developed an interest in understanding the nature of chemical language and the process of personal transformation from subject novice to expert. An aim is to develop strategies that assist students undertaking this transition.

The importance of language in science is established and recognised (Taber, 2013). Chemistry teachers may not see themselves as language teachers and may not be equipped to teach language comprehension skills. This study, however, aims to investigate how linguistic awareness and strategies can impact on chemistry educators. Effective teaching and learning requires effective communication. At the heart of communication is the language used. This is as important as knowing how to use pipettes and burettes when performing experiments. Pyburn, Pazicni, Benassi & Tappin (2013; Chapter 2, Section 2.5, p. 55) demonstrated the value of language comprehension skills to chemistry students. Students with good language comprehension skills but lower chemistry knowledge were able to "catch-up" more successfully than students with lower language comprehension skills. They argue that courses should contain both content and language comprehension skills. Herron (1996) agrees:

"In large measure, teaching reading is teaching concepts, and that part of the teaching of reading is the responsibility of the chemistry teacher, not the reading teacher" (p. 164)

The premise on which this thesis operates is that all non-traditional students at the Foundation Centre are non-native speakers of "*Chemical English*". It explores the development of students' understanding and usage of chemical language as they engage language based activities emphasising corpus linguistics.

1.2 The learning context

The study is situated within the context of the Foundation Centre at a research intensive university in the North East of England. The Foundation Centre is a widening participation initiative that recruits potential undergraduates from the UK and abroad to a four year direct progression programme with routes to all departments within the University. The students study for one year at the Foundation Centre (Year 0) before progressing to their undergraduate programmes upon successful completion of Year 0 with a minimum pass mark of 50%. There are approximately 200 potential undergraduate (Year 0) students of whom around 60 are studying science based subjects. The science based degree routes offered are: biology, biomedical science, chemistry, computer science, engineering, geology, medicine, pharmacy and physics. Typically between three and eight students are recruited to each of the science degree routes. The potential undergraduates are taught a common programme in the first term that then becomes more specialised later in the year. This facilitates class sizes of between 20 – 30 students and enables flexibility for programme changes. All science potential undergraduates study chemistry in the first term. Biology, biomedical science, chemistry, medicine and pharmacy potential undergraduates continue with chemistry for the remainder of Year 0.

1.3 Study design

The study brings the chemistry and second language teaching together to investigate how strategies applied in the context of language teaching impact on chemistry teaching and learning.

A range of linguistic resources and teaching strategies have been devised and embedded within the teaching. A key resource to support this is the development of the Foundation Corpus (FOCUS). FOCUS was incorporated into six different teaching activities (Chapter 3, Table 3.1, p. 79).

Year 0 is intended to be effective preparation for students' undergraduate studies. In a longitudinal aspect of the study, six students are followed beyond Year 0, tracking developments in their use of scientific language and strategies employed.

1.4 Aims and research questions

The aims of the study are to investigate the role language plays in learning chemistry and the challenges this presents to non-traditional students. The study will answer the following research questions.

1.4.1 RQ1 – In what ways does chemical language comprehension ability impact on potential undergraduates' outcomes and success?

The potential undergraduate cohort is diverse with students exhibiting a broad range of knowledge and awareness of chemical language on entry. Therefore, a chemical language diagnostic test (CLDT) was developed to investigate individual students' understanding of different aspects of chemical English (Chapter 4, Table 4.8.3, p. 109). The study tests the hypothesis that students with weaker chemical language comprehension skills are less likely to be successful. The CLDT measures comprehension ability. The CLDT was administered three times during Year 0 generating baseline evidence of students' initial understandings and how these develop with time. Academic outcomes for students have been correlated to their performance on the CLDT. CLDT data are triangulated with explanations from student interviews and eye tracker data to show how knowledge of chemical language relates to students' explanations and reading strategies.

1.4.2 RQ2: In what ways do potential undergraduates' understanding of chemical language develop during a one year, full-time foundation programme?

Using initial CLDT results as a baseline, developments in student understanding could be tracked through Year 0. Previous work (e.g. Cassels and Johnstone, 1985) established the problematic nature of scientific words. Recent studies built on this identifying language comprehension skills as important to student success (Pyburn et al., 2013). The research provides an insight into how chemical language understanding and usage develops over time. The study tests the hypothesis that some categories of chemical language such as non-technical words with dual meaning are more difficult for students to acquire and comprehend than others.

1.4.3 RQ 3: In what ways can teaching strategies utilising linguistic strategies such as corpus linguistics be applied to science education to enhance student understanding of scientific language?

The study adopts the perspective that learning chemistry is like learning a foreign language. Transferability and applicability of second language learning strategies to chemistry are investigated. The study focused on corpus linguistics and data driven learning (DDL) (Johns, 1991; Chapter 2, Section 2.11.1, p. 78). This strategy uses investigative and discovery learning, enabling students to uncover language rules and develop understanding, thereby increasing students' language skills within a chemistry context. The study tests the hypothesis that language focused teaching strategies can improve achievement in chemistry for Year 0 potential undergraduates.

1.4.4 RQ 4: How do potential undergraduates' chemical language usage and learning strategies develop on progression to an undergraduate programme?

The principle objective of the Foundation Centre is to prepare potential undergraduates with the knowledge and skills to be successful in their undergraduate degree programmes. Therefore, the study is longitudinal, following six students into their undergraduate degree programmes (Chapter 6, p. 175). The results of interviews with these students are reported. Three were studying biological sciences, two were studying chemistry and one was a medical student. Semi-structured interviews explored the development of chemical language usage beyond Year 0. This provided data on the impact of the teaching activities beyond Year 0 and investigated the extent to which the students continued to apply linguistic strategies. The study tests the hypothesis that language focused skills acquired in Year 0 are utilised throughout undergraduate studies.

1.5 Structure of the thesis

Subsequent chapters are arranged as follows. Chapter 2 presents a review of the literature on learning and language in chemistry, learning theories and second language learning. The significance and role of language to develop understanding is contextualised within the challenges of learning chemistry. With the aid of specific examples, the utility of scientific words is discussed including how they support or hinder understanding. Anthropomorphic language and dual meaning of scientific words are considered. Ways of "*telling the scientific story*" are discussed as a mechanism for explanation in chemistry teaching. These challenges are considered within the theoretical frameworks offered by social constructivism and learning progressions. The second language learning theories of interlanguage, Spolsky's general model of second language learning and the application of corpus linguistics are also considered.
Chapter 3 describes the design of the teaching activities. The development of a unique corpus of university student writing from foundation to PhD level (Foundation Corpus or FOCUS) is described together with the development of language based activities incorporated into the Year 0 chemistry teaching curriculum.
Chapter 4 describes methodology and design. The structure of the chemical language diagnostic test (CLDT) is explained. Data collection methods also included semi-structured interviews used over time. Eye tracker study data were collected. The chapter concludes with a discussion of the ethical issues and considerations taken into account throughout the research. Chapter 5 presents the results from the CLDT and eye tracker study. In Chapter 6, semi-structured interview data with six students are presented. Chapter 7 discusses findings, suggesting recommendations for teaching practice and opportunities for further research. An evaluation of the limitations of the investigation is presented.

1.6 Summary

This chapter outlined the potential contribution this study can make to teaching and learning in chemistry. It explained the research to be undertaken and sets the national and local context for the study. The next chapter, the literature review, discusses the role of language in science education, the underpinning theoretical framework and second language learning theories.

Chapter 2

Literature Review

2.1 Introduction

On a cold and damp evening during the Christmas holidays of 1860 an expectant crowd gathered in the gas lit gloom outside the Royal Institution in London. They shuffled into the steep banked seating of the auditorium and an excited hush descended as Michael Faraday entered to begin his lecture on "The Chemical History of a Candle" (Figure 2.1).

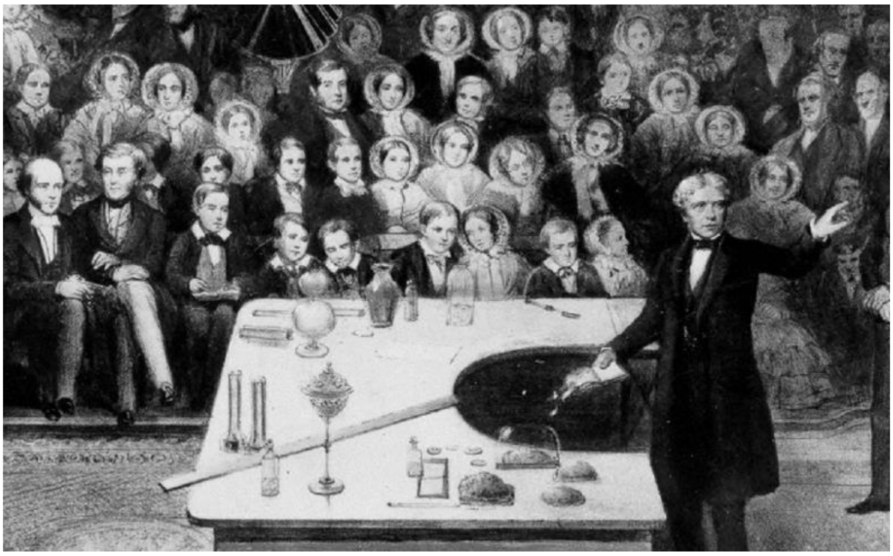


Figure 2.1 Detail from "Michael Faraday lecturing at the Royal Institution December 1855" by Alexander Blaikley (1855)

As he ignited the audience's curiosity he remarked:

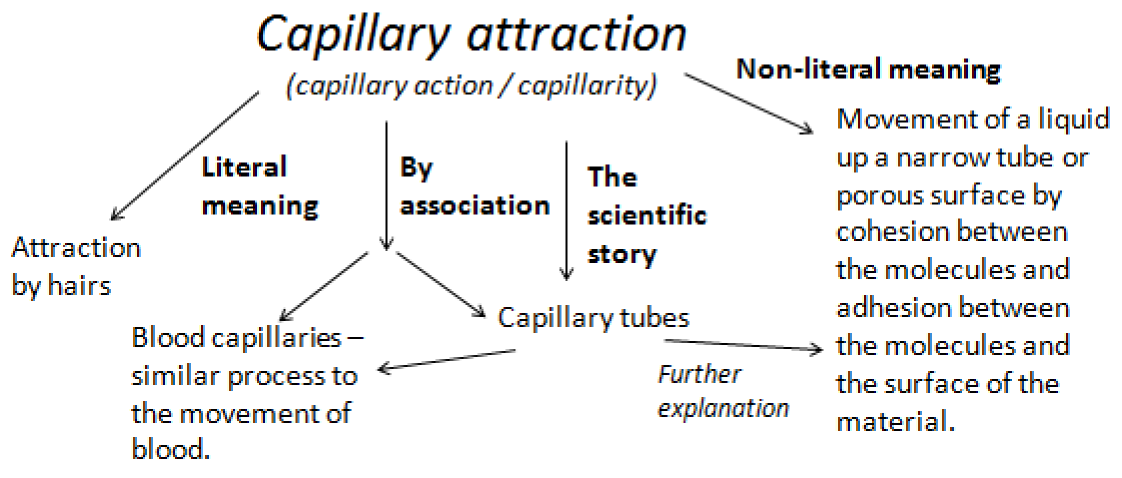
"But how does the flame get hold of the fuel? There is a beautiful point about that – capillary attraction, 'Capillary attraction!' you say – 'the attraction of hairs'. Well never mind the name; it was given in old times, before we had a good understanding of what the real power was." (Faraday, 1861, p. 12)

With this remark about "capillary attraction", Michael Faraday provides a flicker of illumination on the theme of this study; exploration of the importance of words in science and their potential to promote understanding or to confuse and obfuscate. I use this example to illustrate several potential routes for developing understanding of a scientific term (Box 1).

When Faraday introduces this term he immediately dismisses it as misleading because of its reference to hairs (*capillaris* – Latin word for *hairs*). He states that this name was assigned when the true "power" (another interesting choice of word) or mechanism was not known. This suggests that he thought the original assigning of this term was due to a view that movement of liquid was indeed caused by attraction of tiny hairs on the surface. This is our first route via *literal meaning* and knowledge of Latin origins of the English word. Often this is a successful technique, explored within this study. In this case, however, it can lead to an incorrect conclusion as Faraday demonstrates.

To understand the origin of this word and the process it represents, one needs to be aware of our second route to meaning via the *story of science* (Section 2.6, p. 56). The term was ascribed after the 17th Century observation of water rising within a narrow "hair-like" capillary tube due to attraction to the tube walls (Boyle, 1660).

Box 1. *Capillary attraction – the different routes to meaning.*



Two hundred years later, even though knowledge and usage of Latin were commonplace, Faraday recognised potential confusion. The original meaning of the word was lost, leaving listeners to simply learn the explanation. This removes the potential for the term to provide insight and explanation of the process by which water moves up a narrow tube. As such, Faraday tends towards our third route, *non-literal meaning*.

One hundred and fifty years after Faraday, the term "capillary attraction" is used but is referred to as *capillary action*. This is not an improvement, as it implies the *action* of hairs. *Capillarity* is also applicable but retains the "hair" root of the word. Today, knowledge of Latin is less common and meaning is less likely to be derived via this route. The fourth route to meaning is *by association*. In this example, the link to a capillary tube leads to the correct explanation but more commonplace is to think of the tiny blood vessels, *capillaries*. This can lead to incorrect associations with the movement of liquid in blood capillaries.

As chemistry educators, we can imagine ourselves in the position of someone sat in the Royal Institution, listening to Faraday, having little knowledge of science. We must ask ourselves if the language and words used help or hinder audience understanding of the fascinating phenomena we are describing. As an expert, I could suggest these alternatives to Michael Faraday (Box 2).

Box 2. *Alternative explanations of "Capillary attraction"*

1. Exploring the scientific story.

"But how does the flame get hold of the fuel? There is a beautiful point about that – capillary attraction, 'Capillary attraction!' you say – 'the attraction of hairs'. I say 'no – certainly not!' This name was given by the eminent scientist Robert Boyle two hundred years ago when he observed water rising against the force gravity within glass capillary tubes as fine as a hair on your head."

2. Removing unnecessary terms.

"But how does the flame get hold of the fuel? There is a beautiful point about that – the candle wax molecules are attracted to each other and to the wick such that they are able rise inexorably against the force of gravity."

This literature review provides the background and theoretical framework for the study. Sections 2.2 – 2.4 (p. 30 - 44) consider the central role that language has in learning of science and chemistry. I will discuss Johnstone's "triplet" (Johnstone, 1991) as a model of learning chemistry and how language is an important component of this. I review previous research into the linguistic nature of science and chemistry specifically with particular emphasis on scientific vocabulary and general language comprehension. This sets the linguistic context for the present research, showing the need for a chemical language diagnostic test and developing teaching and learning that is informed by and focussed on linguistic theories. Section 2.7.1 (p. 60) identifies Vygotsky's approach to constructivism as the underlying theoretical paradigm and how language and words underpin a student's move into his/her Zone of Proximal Development (ZPD). Section 2.8 considers learner progressions and the role of scientific language within this. Finally, Section 2.10 discusses two theories of second language; Spolsky's general theory of second language learning and interlanguage. I explore how these can be applied to the chemistry context. The literature review concludes by discussing the role of corpus linguistics in teaching and learning.

2.2 The significance of language in science learning

Wellington and Osborne (2001) begin with the following beliefs:

"- Learning the language of science is a major part (if not the major part) of science education. Every science lesson is a language lesson.

- Language is a major barrier (if not the major barrier) to most pupils in learning science." (p. 2)

The first statement refers specifically to the *language of science*, that is, discipline specific discourse. The second statement refers to *language* in a general sense. This point of view raises two immediate and significant implications: firstly, language deficiencies (subject specific and general) impact on student achievement; secondly, science educators require high levels of language awareness and skill in delivering language-focused activities in scientific contexts. Evidence supporting this viewpoint and its implications are considered. Postman and Weingartner (1971) suggest:

"*Almost all of what we customarily call 'knowledge' is language, which means that the key to understanding a subject is to understand its language. What is biology (for example) other than words? If all the words that biologists use were subtracted from the language, there would be no biology".* (p. 103)

Postman and Weingartner (1971) connect several themes relevant to this study. Firstly, they consider that the cornerstone for construction of knowledge is language. Without appropriate language skills construction of meaningful knowledge and understanding is difficult. Secondly, they consider that the *language of biology* is essential to understand the subject (echoed by Wellington and Osborne, 2001).

Lastly, Postman and Weingartner (1971) refer to the *words of biology* and how these are essential for the discipline of biology to exist. As science has progressed and new discoveries made, adaptation of everyday English words for example *salt* and *reduction* and/or production of completely new words such as *electrolysis* and *capillary attraction* to suit scientific meaning have occurred. Subject-specific discourse can alienate people from science, increasing inaccessibility even though the same discourse aided and progressed knowledge about natural phenomena.

The significance of language for educational success received significant government attention with The Bullock report (Bullock, 1975). This offered an overarching exploration and statement for that contributed to shaping school education and science from the 1970s onwards. Bullock stated

"*We must convince the teacher of science, for example, that he has to understand the process by which pupils take possession of the scientific information that is offered them; and that such an understanding involves his paying particular attention to the part language plays in learning. The pupils' engagement with the subject may rely upon a linguistic process that his teaching procedures actually discourage.*" (p. 188)

Bullock advocates all teachers should see themselves as teachers of language, stressing the importance of the nature of teacher-student discourse and becoming skilled in facilitating discussion.

In 1975, the Assessment Performance Unit (APU) formed within the then Department for Education and Science (DES) to promote development of methods for assessing and monitoring student achievement in schools. Between 1978 and 1988, surveys were undertaken of 1.5% of each of the 11 and 13 year old cohorts in England, Wales and Northern Ireland. APU data were used by White and Welford (1988) in their report on the language of science. They summarised pupils' scientific, spoken and written performance and investigated where and how scientific capability interacts with language performance. White and Welford (1988) indicated a direct link:

"*Pupils who were most highly rated in both science and language were found not only to have a good understanding of the Science involved, but also their language was well structured to communicate that understanding to listeners or readers*" (p. 19)

White and Welford support Postman and Weingartner (1971), suggesting that performance in science is directly correlated with language skills. Furthermore, they establish a link between language and pupils ability to *communicate* understanding. The relationship between an individual's *internal* understanding and his/her *external* explanations is important; I return to this later when discussing interview data in Chapter 6.

Bullock (1975) continues to influence science education practice in curriculum developments in England. For example, the National Curriculum (Department for Education, 2015) states:

"The national curriculum for science reflects the importance of spoken language in pupils' development across the whole curriculum – cognitively, socially and linguistically. The quality and variety of language that pupils hear and speak are key factors in developing their scientific vocabulary and articulating scientific concepts clearly and precisely." (p. 57)

This statement highlights that science teachers must emphasise scientific language in terms of their explanations and helping pupils develop. The role of science teachers as supporters of language learning has also been recognised in the US. For example, Standard 4 of Science and Technical Subjects for grades 11-12 states that students should be able to

"*Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context*" (Council of Chief State Officers, 2010, no page number assigned).

Additionally, to assist students meeting the *Next Generation Science Standards*, teachers are encouraged to emphasise academic language in classroom discourse and learning (NGSS, 2016). Therefore, science teachers require training to develop linguistic skills and effective pedagogic strategies.

The importance of scientific literacy has been recognised globally. The Programme for Individual Student Assessment (PISA) assessed scientific literacy (OECD, 1999, 2003, 2006, 2015). The Organisation for Economic Cooperation and Development (OECD) define scientific literacy as:

"…the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen.

A scientifically literate person, therefore, is willing to engage in reasoned discourse about science and technology which requires the competencies to:

1. Explain phenomena scientifically:

Recognise, offer and evaluate explanations for a range of natural and technological phenomena.

2. Evaluate and design scientific enquiry:

Describe and appraise scientific investigations and propose ways of addressing questions scientifically.

3. Interpret data and evidence scientifically:

Analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions." (OECD, 2015, p. 7)

This emphasis implies individuals must be scientifically literate to engage meaningfully with many aspects of a modern, technological society. Language is the common thread throughout as *reasoned discourse, explaining, describing* and *evaluating* are emphasised. Hence, the significance of enhancing understanding of language learning in science is clear.

2.2.1 The significance of language in chemistry learning

The importance of language learning in chemistry has been considered by a number of authors in recent years (Laszlo, 2013, Markic & Childs 2016 and Taber, 2015). This section considers previous research on learning in chemistry arguing for language as an enabler of meaningful learning.

Students often find chemistry difficult (Johnstone, 2009) particularly at introductory levels. Multiple reasons are established including: challenges developing formal explanations for phenomena at the macroscopic level; the requirement to connect macro- and sub-micro levels (Johnstone's "multi-level" thinking, 1991); the requirement for abstract thought with explanations involving "particles" at a sub-microscopic level; which behave differently from macro-scale particles such as sand grains and the potential for information overload of working memory (Johnstone, 2009).

Johnstone (1982, 1989, 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 (Figure 2.2) 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.

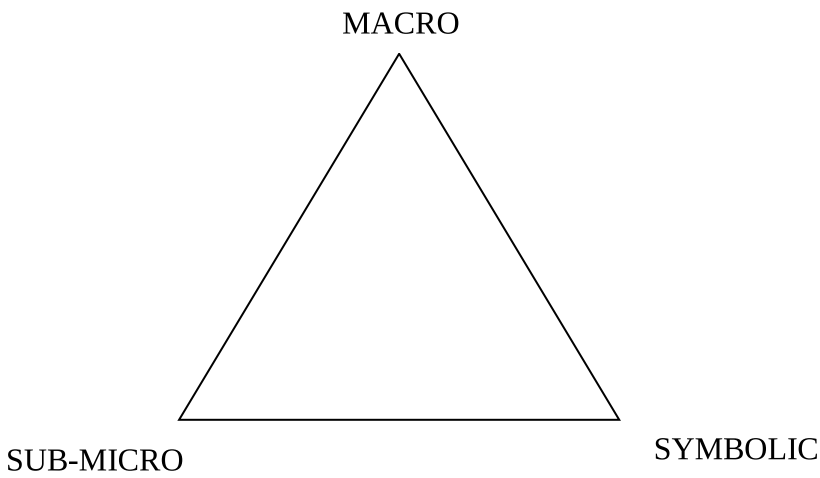


Figure 2.2 The chemistry learning triplet (Johnstone, 1991)

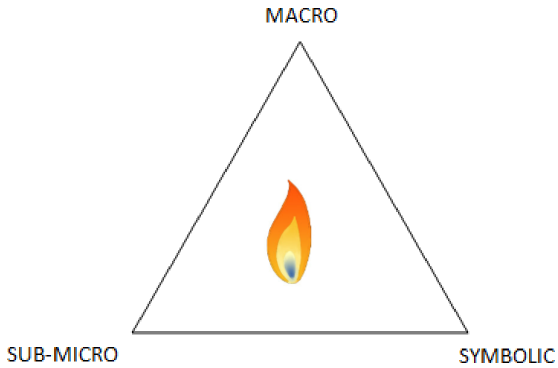
At this point, let us return to Faraday's candle and consider how this example fits this model. I invited students in one of my classes to suggest words and symbols for each apex (Box 3). Vocabulary generated ranged from names of objects and elements such as *oxygen*, to processes, for example *combustion*, and concepts such as energy changes in a chemical reaction. Levels of scientific language are apparent e.g. *burning* and *combustion* or *energy* and *enthalpy* change. Questions arise about the extent of students' understanding connections between these words and any shared meaning between teacher and students. Knowledge of scientific words is tested in the diagnostic test developed for this study (word choice section – Chapter 4, Section 4.8.3, p. 111).

At the symbolic level, students may not produce correct chemical formulas or equations but they were aware these represented chemicals.

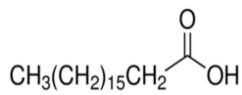
Box 3 *Vocabulary and symbols generated by potential undergraduates about a candle flame.*

Macroscopic: Light, heat, exothermic, burning, combustion, energy, enthalpy change, change of state, solid, liquid, gas, chemical reaction, reactants, products

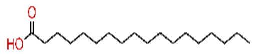
Sub-microscopic: Molecules, fuel, octa-decanoic acid, stearic acid, oxygen, carbon dioxide, electrons, clouds, shells, covalent bonds, activation energy, breaking, forming,



Symbolic:
ΔH



$C_{18}H_{36}O_2(g) + 26O_2(g) \rightarrow 18CO_2(g) + 18H_2O(g)$



Johnstone (1991) suggests students may be viewed as operating within the triangle. I envisage the students repeatedly shifting around the triangle as they move between the levels.

An alternative model was proposed by Jensen (1995; 1998). He classified concepts and models in chemistry in dimensions of *composition and structure, energy* and *time* (Table 2.1). These dimensions correspond, historically, to major chemical revolutions. Drawing on historical perspectives of the development of chemistry relates to Sutton's ideas of telling the scientific story and words as interpretive tools (Sutton, 1992; Section 2.6, p. 56). Each of these dimensions can, in turn, be considered at the *molar*, the *molecular* and *electronic* levels. The molar level is synonymous with Johnstone's macroscopic level. Both the molecular and electrical levels encompass Johnstone's sub-microscopic level. Johnstone's symbolic level is represented within the molar, molecular and electronic levels. Jensen's model has received less widespread attention than Johnstone's triplet. This may be because it is a logical structure to chemistry teaching that could be a basis for curriculum design, whereas Johnstone's triplet is a testable model that provides a framework for interpreting student learning. This is demonstrated in Box 3, where Johnstone's triplet can be used to analyse the language usage to discuss a candle flame. The same example could be analysed using Jensen's molar, molecular and electrical levels. It would be difficult to incorporate the different dimensions and they are less informative in terms of understanding development of student meaning.

	Composition & Structure Dimension	Energy Dimension	Time Dimension
Molar Level	1. Relative composition of simple & compound pure substances, solutions & mixtures. Empirical designation of allomorphs (state, color, crystal form, α, β, etc.).	4. Calorimetric entropies & heats of formation. Free energies & equilibrium constants.	7. Experimental rate laws. Experimental Arrhenius parameters and/or entropies and heats of activation.
Molecular Level	2. Absolute & structural formulas. Rationalization of allomorphs as variations in either absolute composition (polymers) or structure (isomers).	5. Molecular interpretation of entropy. Interpretation of heats of formation in terms of heats of atomization, average bond energies, etc. Molecular mechanics.	8. Molecular reaction mechanisms. Molecular view of activation entropies and activated complexes.
Electrical Level	3. Electronic formulas (Lewis str. & electronic config.). Variations in either electronic or nuclear composition (ions & isotopes) or structure (excited states).	6. Calculation of energies based on electronic structure. Interpretation of spectra. Calculation of heats of atomization, spectroscopic entropies, etc.	9. Ionic & photochemical reaction mechanisms. Isotope effects. Calculation of activation energies. Electronic reactivity indices.

Table 2.1. The logical structure of chemistry (Reprinted with permission from Jensen, 1998, p. 680. Copyright 1998 American Chemical Society)

Johnstone's model has been modified in a number of ways (Taber, 2013; Talanquer, 2011). For example, the triangle was developed to include the human element component of chemistry learning (Mahaffy, 2006). Chiu (2012) added language in recognition of its role in facilitating or restricting learners' views of the chemical world and meanings of words (Figure 2.3).

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Figure 2.3 Modifications of Johnstone's "triplet" (Chiu & Chung, 2013)

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. He argues 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 highlights 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 (Figure 2.4).

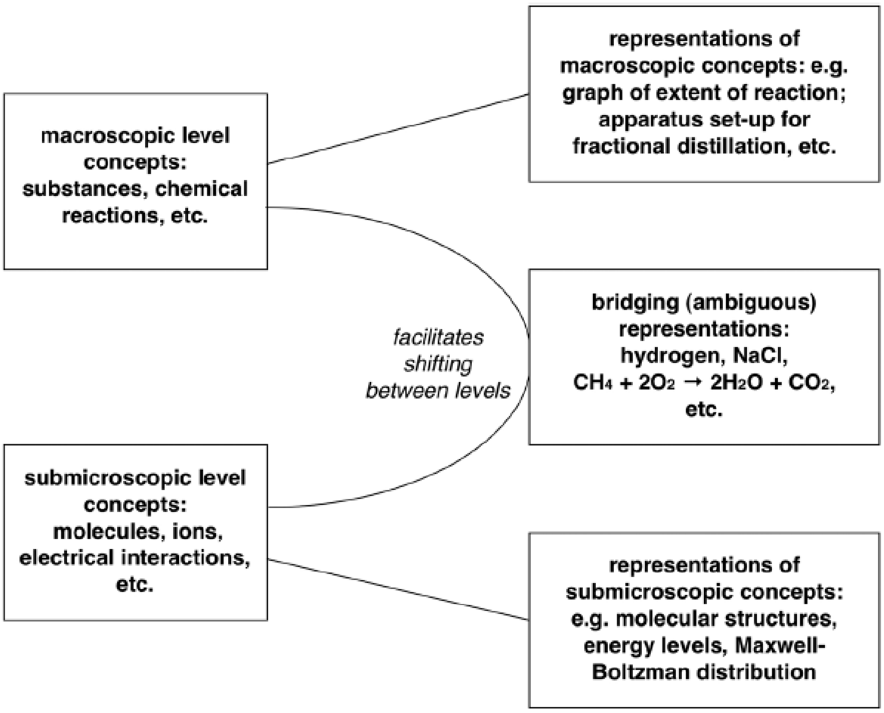

Figure 2.4 The symbolic domain for supporting the development of explanations relating the macroscopic and sub-microscopic levels (Reproduced from Taber, 2013 with permission from The Royal Society of Chemistry)

The language of chemistry as an enabler for students to interpret and explain chemical phenomena at the macroscopic and sub-microscopic level is central to this thesis.

2.3 The role of language in science teaching

Sutton (1992) argues there are two ways of using language in science teaching; namely, *interpretive* and *labelling*. A labelling approach is definitive, assumes meaning is understood and implies there is only one way to "see" events. An interpretive approach is exploratory, recognises there is room over how an idea can be expressed and consciously uses language to help people see a topic in new ways *i.e.* it has a persuasive role.

The interpretive approach is inspired by the development of new words and language to describe novel scientific discoveries. For example, when Robert Hooke (Hooke, 1665) first observed thin slices of cork through his microscope in 1665 he considered a variety of words to describe the structures he observed, including *pores*, *boxes* and *bladders* before arriving at *cells* (Sutton, 1992). Hooke took *cells* from existing uses to describe compartments in a honeycomb and the monks' rooms in a monastery. *Cells* become an automatic label shaping how we think about the smallest individual units of living tissue. However, in Hooke's era, this interpretation was under development, not taken for granted. The labelling approach is characterised by presentation of words as statements of fact such as "atoms are made of protons, neutrons and electrons", or "the nucleus of each living cell contains chromosomes", limiting interpretation. Sutton states:

"*In this way some of the ideas of science get transformed into arbitrary information to be learned; they no longer retain the status of puzzles at all, and scarcely seem to merit being puzzled over. If pupils are exposed to words in that way over and over again, they can get little sense of scientific language as an instrument of interpretation, and little incentive to use it themselves for sorting out ideas*". (Sutton, 1992, p. 51)

An implication is that if students appreciate scientists' linguistic efforts when developing explanations and ideas they may be more confident to participate in personal internal and external negotiations of meaning. Sutton (1992) argues that, over time and through repetition, words progress from interpretive statements to labels. Michael

Faraday's remark about *capillary attraction* illustrates this; the term is not considered interpretive, but a label for a process.

Drawing on science studies by Bazerman (1988), Lemke (1990), Medawar (1974), Shapin & Schafer (1985) amongst others, Sutton (1998) developed ideas for the role of language in science teaching (unshaded columns in Table 2.2). The first column, "a system for transmitting information" is the labelling role while the second column is the interpretive role. Comparing these, the implications for learning and student understanding of scientific endeavour are apparent. In the final row "how language is thought to work in scientific discovery", Sutton suggests that, under the labelling route, students' perceptions will comprise a process of discovery giving an event a label. The interpretive route encourages appreciation of how word choice influences perception, emphasising some aspects. Under the labelling route, a process is outlined in which a speaker *tells* and a listener *receives* with focus on transmission from teacher to learner. Under the interpretive route the speaker *persuades*, the listener engages in *making sense of meaning* (dependent on clear transmission by the speaker) and re-expressing ideas. This is an argument for the interpretive route but, as Sutton (1992) acknowledges, expecting a teacher to follow this route consistently would be unrealistic. Overuse could be counterproductive while labelling may be appropriate on occasions. In addition, interpreting would be time consuming and may distract from rather than support learning. Teachers may, as Jensen (1995; 1998) pointed out, consider historical approaches as too general or philosophical to meet the needs of a chemistry student. Relevant and significant examples need to be considered for this to be successful. However, this captures an approach to language in the classroom that develops student participation and appreciation of the nature of science.

Carlsen (2007) added a third role of language as "a tool for participation in communities of practice" (p. 69) based on social constructivism (Table 2.2, shaded column). This emphasises shared understanding between speaker and listener, which extends Sutton's interpretive role. Carlsen and Sutton highlight the persuasive role of scientific language, noting that shared understanding emerges from learners' re-expressing ideas. The speaker's role is persuading and exploring in ways that make sense of the listener's cues, leading ultimately, to joint contributions to a shared position. Carlsen's viewpoint is from the perspective of social discourse between scientific communities. Scientists debate understanding based on experimental evidence to achieve consensus of understanding. This situation arises when two groups are equipped with subject-specific language and understanding to participate. Typically, within the classroom, however, the challenge is greater as shared understanding is developed between the teacher (expert) and the student (novice).

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Table 2.2 Changing perspectives on the role of language in science and science teaching (Carlsen, 2007; Sutton, 1998).

Exceptions, however, may occur. Crawford, Kelly and Brown (2000), for example, describe how an elementary school teacher adopts the role of co-investigator with students when developing scientific investigations relating to marine animals in a classroom aquarium. During the enquiry process, students were given decision making roles and questions were devised. The teacher engaged a marine scientist expert to respond to students' questions. Through class discussion, a course of action was decided, results obtained and discussed. In this classroom discourse process teacher and students progressed to shared understanding. Mortimer and Scott (2003) stress the importance of the persuasive nature of teaching performance within the social plane of the classroom (p. 19). Edwards and Mercer (1987) state that the ultimate aim of all education is the development of shared understanding. They advocate the interpretive role of language in which meaning is achieved through negotiation and persuasion. Their studies of primary school aged children lead them to advocate there should be:

"*a greater emphasis on the importance of language and communication in creating a shared conceptual sense of meaning*" (p. 169).

For students to participate successfully within this framework they must use the *social language of science* (Mortimer and Scott, 2003). This is based on Vygotsky's perspective on development and learning occurring in social contexts (Vygotsky, 1962; Section 2.7.1, p. 60) and the concept of social language developed by Bakhtin:

"*…a discourse peculiar to a specific stratum of society (professional, age group etc.) within a given social system at a given time*" (quoted in Holquist, 1981, p. 430)

Students in this study have an *everyday social language* that provides the means for day-to-day communications. Students are required to develop a shared, common understanding of social language of the scientific discipline they plan to study. Mortimer and Scott (2003) describe "meaning making" as:

"...each participant bringing together ideas which they already have (their existing points of view), along with those 'new' ideas presented in the talk...meaning making can be seen to be a fundamentally dialogic process, where different ideas are brought together and worked upon." (p. 3).

Students' responses often reveal confused explanations which are developed and improved through negotiation and clarification by other students and the teacher. Shared understanding is an awareness of students' current understanding and how to develop this towards the desired scientific understanding by working within their zones of proximal development (Section 2.7.1, p. 60).

Lemke (1990) focused on learning science as students learning to talk science through classroom discourse. He explored the semantics of scientific language in terms of the ways words and symbols combine to create meaning. He stated:

"When the people with whom we are trying to communicate use language differently, use it in ways that make sense of a subject differently than we do, communication becomes much more difficult. Science teachers belong to a community of people who

already speak the language of science. Students, at least for a long time, do not." (Lemke, 1990, p. x - introduction)

Lemke (1989) recognised a tension between "scientific" and colloquial or everyday ways of speaking. He commented on students being engaged in lessons when the teacher uses less formal or unscientific language (p. 16). Lemke (1990) described scientific language as "foreign" to students who, he argued, will understand ideas better if they are expressed in the language they use themselves, ordinary colloquial language. The student will need to learn to be "bilingual" in colloquial and scientific English (p. 172). The teacher should express conceptual knowledge in colloquial and scientific English wherever possible and distinguish between these explicitly. As students are exposed to these two languages, the students will develop a hybrid or "interlanguage" (p. 173). This is comparable to Selinker's use of "interlanguage" in relation to second language learning (Selinker, 1972; Section 2.10.2, p. 75). Lemke (1990) states that students should engage in regular translation practice from colloquial to scientific English and vice versa. Mortimer and Scott (2003) refer to how new scientific words can feel alien or foreign in students' mouths. Using the example of *molecule*, they provide an example where a student alternates between *particle* and *molecule*:

"that the particles have...that the molecules, that the particles have energy and there is space between them" (p. 20).

The student is demonstrating uncertainty and is beginning to develop meaning of *molecule* in this context.

Studies have identified that students who use colloquial language may find it difficult to access "foreign" scientific ways of speaking (Ballenger, 1992, 1997; Barton, 2003; Delpit, 1988; Gee, 2005; Heath, 1983). Bahktin (1981) termed transitionary discourses as "hybridisation" and described them as:

"a mixture of two social languages within the limits of one utterance, an encounter, within the arena of an utterance between two different linguistic consciousnesses" (p. 89).

Studies describe the occurrence of hybrid discourse and hybrid discursive spaces (Ash, 2008; Bacquedano-Lopez, Solís, & Shlomy Kattan, 2005; Gutiérrez, Baquedano-López, & Tejeda, 1999; Lopez & Turner, 1997; Leander, 2002; Miano, 2004). Ash (2008) refers to hybrid discourses in a study of twenty eight 11-12 year-old students in an urban school located in Northern California, U.S. In one situation a student is discussing about otters, an aquatic mammal. The student alternates between every day and scientific language while explaining mating. She said:

"You know how I told you earlier, the [male] sea otters just go to a ***female*** *and mate with them and leave them and go mate with another? But they can tell when the* ***lady****'s not ready for mating.... The men usually go on their own, after they mark their territory, they go to the women's rafts, find the lady, and mates her"* (p. 18).

Ash (2008) argues that fluctuation between scientific terms such as *female* and everyday terms such as *lady* demonstrates a hybrid discourse that suited the student's purpose. In this case scientific and everyday alternatives exist that convey similar meaning *("female"* and "*lady")*. Hence, shared understanding can be achieved using this hybridisation. However, in other situations there are no direct translations of terms between the scientific and the everyday. For example, no obvious everyday terms are interchangeable with *electron*, *nucleophile* or *activation energy*.

Edwards and Mercer (1987) provide examples of shared vocabulary in teacher/student discourse. This occurs when the teacher introduces scientific vocabulary in an understood context as an alternative to everyday terms. In a discussion of pendulums for example (p. 153), the students use terms such as "weight" and "hang straight down from one finger". The teacher uses these terms but also introduces scientific terms such as "mass", "suspended" and "from a fixed point". The scientific terms are not explicitly defined but the teacher models their appropriate use, with the aim that students start to use the scientific terms themselves.

2.3.1 Anthropomorphic language

Anthropomorphism is an extension of animism and is the term used when human feelings and emotions are assigned to non-living things. Anthropomorphic language may be employed by teachers to aid understanding (Taber and Adbo, 2013) and may initially make the abstract world of molecules and ions accessible to learners (De Jong and Taber, 2014). Taber (1998), in an interview study with 16-19 year-old English students, reported anthropomorphism in students' explanations of basic chemical concepts. Based on understanding bonding in terms of the "octet rule" and atoms achieving full outer shells of electrons, Taber (1998) argued that explanations were phrased in terms of what atoms “want” or “need”. Thus language choices were driven by providing explanations for the concept so students could access and comprehend, even if adopting an unscientific position. Taber and Adbo (2013) report high levels of anthropomorphic language in the explanations of chemistry phenomena by a group of 16 – 18 year old Swedish science students. Taber and Watts (1996) distinguish between *strong* and *weak anthropomorphism*. Anthropomorphic language is weak when the user is aware of language use and does not intend it to be a sufficient explanation. Taber and Watts (1996) suggest that this form of anthropomorphic language is useful when helping students become familiar with abstract concepts. Strong anthropomorphism provides causation for the event, a teleological explanation, rather than a starting point for thinking about a concept. In this way anthropomorphic language helps provide a transitionary explanation. Taber and Watts (1996) raise the concern, however, that habitual use of anthropomorphic speech can lead to this becoming the explanation rather than acting as a temporary placeholder. Talanquer (2007) suggests that anthropomorphic language that is not intended as a formal explanation can help students organise their knowledge around major ideas in science.

I shall now discuss research that has specifically examined words of science and chemistry.

2.4 The words of science

This section considers previous research investigating students’ understandings of scientific words and difficulties they present.

Wellington and Osborne (2001) proposed three types of words make up ‘scientific language’. These can be grouped into “scientific”, “semi-technical” and “non-technical” (Table 2.3). Positioning words within these categories is open to debate. For example, the distinction justifying classifying *continuous* as semi-technical and *linear* as non-technical may not be immediately apparent. However, focusing on the broad message conveyed by such analysis is more important. There is a wide range of words a science student has to understand, many with more than one meaning.

Scientific words		**Semi-technical words**		**Non-technical but widely used in science**	
Unique to science	*Everyday meanings*	*One meaning*	*Dual meaning*	*One meaning*	*Dual meaning*
cathode	substance	emit	light	linear	standard
electrolysis	field	repel	positive	source	contrast
anode	conduct	displace	negative	external	effect
electron	mass	deflect	valid	limit	volume
neutron	potential	particle	neutral	sufficient	crude
ion	energy	continuous	contract	adjacent	complex

Table 2.3 Wellington and Osborne's (2001) scientific word groupings

The difficulties this may present are exemplified in the teacher/pupil dialogue extract from Mortimer and Scott (2003) in Box 4.

Box 4. *Like copying something on a synthesiser* (Mortimer and Scott, 2003, p. 30)

Teacher: Plant feeding. It's called photosynthesis. Now what does this word mean...literally? What does synthesize mean? Synthesis. If you synthesise something what do you do? Robin?

Robin: Like copying something on a synthesizer.

Teacher: Eh?

Robin: Like copying something.

Teacher: Copy? No!

Student: Making up.

Teacher: To make up. Yes, to make up, to make. If you synthesize something you make something, manufacture something. I suppose your synthesizer is for making music isn't it?

Robin: No, [in patient tone] it's for copying music.

Teacher: Yes, making music. Tunes.

The text in Box 4 shows the teacher is trying to connect the scientific meaning of *synthesize* with its everyday use, but the student regards their *synthesizer* as *copying* rather than *making* music. Sutton's interpretive role for language suggests that, a linguistically skilled teacher would take the idea of *synthesis* to mean *copying* as a starting point and explore if it was the most appropriate meaning in this context. *Making up* has multiple meanings such as applying cosmetics or inventing a story. The teacher adjusts the verb from *to make up* to *to make* so that the meaning corresponds to *synthesis*. This exchange illustrates complexities of linguistic challenge.

Eiss (1961) recognised difficulties caused by words in having different meanings in separate sciences, such as *weight* in biology and physics. Gardner (1972) carried out an extensive study in this area. He tested over 7000 Australian 11 -16 year old students' understandings of 600 words considered to be essential or valuable to school science by science teachers. The words selected were non-technical and unlikely to be explicitly taught, for example, *abundant, affect, conception, partial* and *phenomenon*. He found words science teachers used frequently were inaccessible to students including: *consecutive, spontaneous, standard* and *stimulate*. This highlighted students challenges with "normal" English words used in scientific contexts.

Cassels and Johnstone (1980) identified a limitation of Gardner's work, noting results were based on one question only testing each word. These authors recognised that meaning is determined by context. They undertook a two-year study in the UK with 25000 secondary 11 to 17 year olds presenting them with words in multiple scientific contexts. Cassels and Johnstone (1980) established similarities between Australian and UK students' understandings. They report that a word used in a scientific context is harder to understand than the same word in a non-scientific context. They highlighted word combinations that result in an expression with a difficult meaning. For example, students correctly defined the word *invert* when referring to an egg timer, but only 50% were able to complete the statement "to invert an object means" with the phrase "to turn the object upside down". The egg timer context provided a clue about the meaning of the key word. Similarly, the word *external* when used with *TV aerial* was easy to understand but proved difficult when linked with *skeleton*. Cassels and Johnstone (1980) argue that moving to a scientific context requires students to interpret a completely new context to find meaning for a word. Cassels and Johnstone (1983) discuss the teacher role in seeking connections between new and existing vocabulary and the importance of linking new information to existing relevant concepts. They draw on Ausubel (1963) who suggested that meaningful learning occurs only if new information is linked to existing relevant concepts.

Cassels and Johnstone (1980) demonstrate the importance of word context enabling a student to deduce meaning. This principle underlies data driven learning (Section 2.11.1, p. 78) that enables students to experience a word within multiple contexts and gain a deeper understanding of its meaning. Cassels and Johnstone (1985) refined their work, focusing on 95 words reported as especially problematic in their previous study. This list included words from "non-scientific" English applied in a scientific context. These authors designed multiple choice questions to test understanding of these words in four formats in 30 000 11 – 18 year old respondents. Table 2.4 shows exemplar data for the word *abundant*. This illustrates the importance of context and environment surrounding a word. In question type 1, for example, the student needs to know the word meaning without contextual clues whereas in question type 4 the non-scientific context of "apples" is used. In Question type 3 a scientific context of gases and reaction chemicals is provided.

Synonym questions (Type 1, Cassels and Johnstone, 1985) appeared to generate most difficulties. Other question styles placed the word in context which may have carried sufficient information to give cues. Words identified as "weak" or "very weak" in terms of understanding are shown in Table 2.5. This list includes words where the opposite meaning was selected, such as *negligible* meaning *a lot*. Evidence for lack of precision in student understanding was apparent when choices were swayed by the context. Cassels and Johnstone (1985) express concern:

"*This can have very serious consequences for concept development. It may be in language that the origins of alternative frameworks lie. Loose language must give rise to loose reasoning and strange conclusions, particularly if opposites emerge"* (p. 14).

From the teacher's perspective, lapses into inconsistent and imprecise use of language can impact significantly on student understanding. From the students' perspective, developing precise and appropriate language use enables clarity of conceptual understanding. Taber and Coll (2002) make a similar point in relation to discussions that move between the macroscopic and microscopic facets of bonding.

Question type	Example
1) A one word synonym without context.	Abundant can mean a. Exact b. Perfect c. Scarce d. Plentiful
2) The word is incorporated into four sentences only one of which is correct.	Which sentence uses the word abundant correctly? a. The house was abundant for the shops b. The police towed away the abundant car on the motorway. c. The referee brought the match to an abundant end. d. The farmer was pleased with his abundant crop of potatoes.
3) The word is used in a science context.	There was an abundant supply of gas to the reaction chemicals. This means that a. There was a shortage of gas. b. The supply of gas was just enough for the reaction. c. The gas was not suitable for the reaction. d. There was plenty of gas for the reacting chemicals.
4) The word was used in a non-science context.	Apples were abundant last year. This means that a. They were larger than normal b. There was a poor supply of them c. They were ready for picking earlier d. There were plenty of them.

Table 2.4 Four multiple choice questions testing the meaning of a*bundant* in varied contexts (Cassels and Johnstone, 1985).

Textbook language must also adopt precise and appropriate forms. Pekdag and Azizoglu (2013), for example, studied semantic mistakes in chemistry textbooks from the USA, France and Turkey relating to “amount of substance”. They highlight interchangeable and incorrect uses of the *mole* and *amount of substance* (Box 5) and usage of element, compound, atom and molecule in ways that lead to students' confusion at macroscopic, microscopic and symbolic levels. Pekdag and Azizoglu (2013) state:

"that these mistakes are not only capable of obstructing a student's scientific understanding and learning of the quantity of amount of substance and its unit the mole but also have the potential of creating misconceptions as well." (p. 123)

This can impact on students' ability to operate at the macroscopic, sub-microscopic or symbolic level. Students may confuse verbal and audio expressions using terms incorrectly from these levels.

Box 5 *Appropriate use of the unit, "the mole".*

Consider the two forms of the following question:

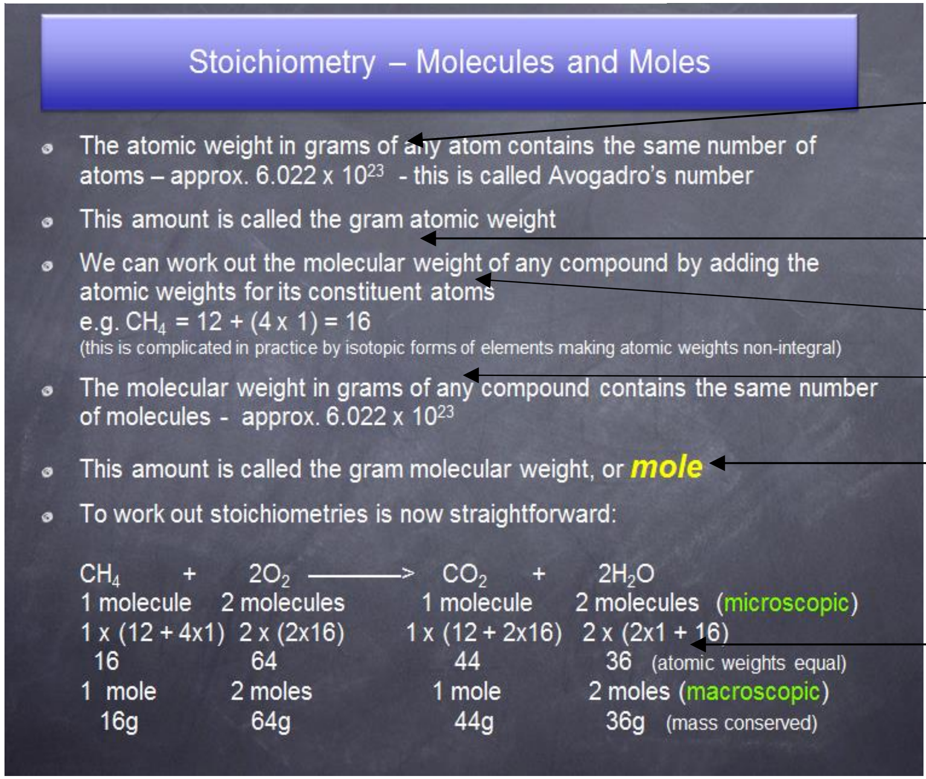
1. *How many moles are there in 6g of carbon?*

2. *What is the amount of substance, in moles, in 6g of the element carbon, C?*

The first form of the question may commonly be heard being uttered in chemistry classrooms but is semantically incorrect. According to the SI definition of the mole, if the amount of substance is to be expressed by associating it with physical quantities then the macroscopic form of the substance (element) should be expressed (Pekdag and Azizoglu, 2013) *i.e.* 6g of the element carbon. Furthermore, in sentence 2, "mole" is now correctly contextualised as the *unit for the measure* of the amount of substance rather than as the *actual measure* as suggested in sentence 1. Mole becomes subsidiary to the concept of amount of substance. The phrase "in moles" can be omitted completely and it would remain semantically correct. This puts *the mole* into a similar context to other units of measure. For example, it is more common to say "How tall are you?" rather than "How many metres are you" or "Measure the angle in this triangle" compared to "How many degrees is this angle?" Mathematics does not overemphasise the meaning of the unit e.g. "metre" or "degree". These terms are the unit of measurement of length or angle just as the mole is the unit of measurement of amount of substance. Good science is dependent on precision, in the same way good science teaching is dependent on linguistic precision.

Box 6 is a Powerpoint® slide used in a lecture teaching first year university undergraduates typically aged 18 – 19 attending a "chemistry for biologists" module. It illustrates how language can create confusion. The text requires students' to oscillate repeatedly between macroscopic and sub-microscopic levels, attempting to learn from an array of scientific terms used imprecisely. This places high demand on working memory to comprehend this content (Figure 2.5).

Box 6 *Mixed levels and information overload.*



Mixture of macroscopic quantities (atomic weight in grams i.e. molar mass) and sub-microscopic entities (atom).

Unclear which amount is being referred to and a confusing macroscopic term that would be unfamiliar to new undergraduate students.

Mixture of sub-microscopic (molecular weight) and macroscopic (molecular weight in grams).

Implies gram molecular weight and mole are synonymous.

Showing comparison between sub-microscopic and macroscopic. Vague use of "atomic weights equal".

Total number of scientific terms used = 18

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In a smaller scale study, Pickersgill and Lock (1991) investigated the use of thirty non-technical words taken from Cassels and Johnstone (1980). About 200 students completed an assessment with questions in four formats (as shown in Table 2.4). Replicating previous findings, synonym questions proved to be least understood. Pickersgill and Lock (1991) identified instances of pupils taking the opposite meaning to that which was intended as well as choosing words that sounded or looked similar, such as *retract* and *contract*.

Cassels and Johnstone (1985)	Pickersgill and Lock (1991)
abundant[1]	abundant
contract	contract
spontaneous	spontaneous
converse	converse
adjacent	adjacent
valid	valid
incident	incident
negligible	negligible
emit	emit
linear	linear
random	liberate
contrast	factor
composition	concept
complex	tabulate
exert	conception
component	disintegrate
sequence	stimulate
relevant	retard
	convention
	diversity

[1]Shaded rows indicate the same words identified in the both studies.

Table 2.5 Problematic words used in science identified in two separate studies.

However, a likely teaching scenario is that students will be presented with words in appropriate contexts so this test may be unrealistic. A better test is of students' understandings in subject specific situations. In addition, opposite meanings must have been selected in the synonym question where no context is given (see question type 1 in Table 2.5). The student cannot use clues to determine meaning but must rely on "dictionary-like" recall to know a definition.

Johnstone and Selepeng (2001) undertook a small scale study with 15-16 year olds in a Scottish school in which about 50% of students were non-native English speakers. Their findings, similar to Cassels and Johnstone (1983), showed evidence for students selecting words with opposite meanings. Examples included *source* which was interpreted as *where it went to*, and the association of *abundant* with *shortage*. Johnstone and Selepeng (2001) consider the impact of linguistic limitations on an individual's learning. Drawing on the concept of working memory, they refer to an information-processing model (Figure 2.5) suggesting that students struggling to learn science in English as a non-native speaker lose at least 20% of their reasoning capacity. This arises because mental working capacity is utilised on translating and processing language, reducing information reaching long term memory.

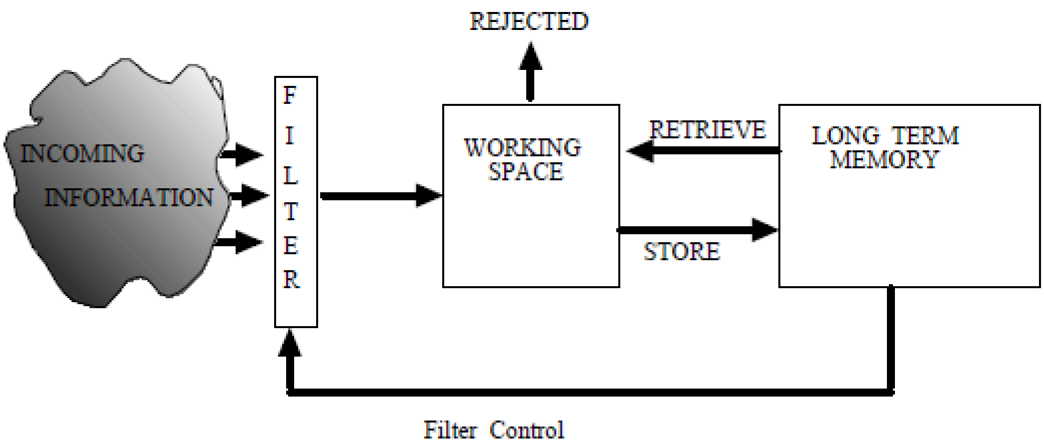


Figure 2.5 The Information Processing Model (Reproduced from Johnstone and Selepeng, 2001 with permission from The Royal Society of Chemistry)

The impact linguistic limitations have on students' working memory relates to the ability to process incoming information. However, this does not address an individual's ability to use developing language to construct meaningful conceptual understanding.

Ali and Ismail (2006) undertook a small scale study in Malaysia which supported Johnstone and Selepeng's (2001) findings. They studied ninety one 14-year old students from three subject streams: arts (26 students), engineering (30) and science (35). Their study tested students' usage of 25 non-technical words identified by previous studies as challenging, presenting these in scientific and non-scientific contexts. Although the science students scored highest, this group achieved only 50% correct compared to 24% for the engineering students and 20% for the arts students. Despite the engineering and science students received specific "English for Science and Technology" lessons, the low scores indicate continued difficulty to develop appropriate scientific meaning.

Song and Carheden (2014) undertook a small-scale qualitative study with thirteen female non-major pre-health, pre-nursing and sport and exercise undergraduates in the US. They investigated understandings of eleven words with dual everyday and scientific meanings, for example, *solution, polar, reduction* and *organic*. These words comprise a dual meaning vocabulary (DMV) (Song and Carheden, 2014), similar to Gardner's (1972) non-technical vocabulary. These words were taught explicitly in chemistry contexts in this study. Song and Carheden (2014) presented single words in isolation on flash cards to students who explained what these mean. They found the everyday DMV meaning remained rooted in students' understandings even post-instruction. The authors ascribe this to infrequent usage of these terms in scientific contexts. Students gave immediate responses relating to everyday meanings, as the words were presented in isolation, in the absence of a chemical context. However, scientific understandings were probed at interview, revealing students had difficulties to producing scientific explanations for these words.

Cink and Song (2015) undertook case studies of four ethnically diverse college students (aging from early to late twenties) to investigate appropriation of scientific vocabulary. They found that students successfully appropriated the scientific meanings of thirteen DMV words (*acid, base, concentration, condition, energy, flask, heat, metal, mole, react, reactant, reaction* and *salt*). Cink and Song (2015) attribute the students' success to providing them with multiple opportunities to practice DMV words in scientific contexts.

Jasien (2010) also used interviews to explore student contextual understandings of the term *neutral*. He undertook twenty interviews with students and presented them with the following five sentences:

“*1. The liquid in the glass is a neutral solution.*

2. The referee is a neutral third party.

3. The liquid in the glass consists of neutral molecules.

4. Pure water is considered neutral.

5. The Lewis structure indicates that the acid molecule is neutral.” (p. 33)

Sentences were presented consecutively. Students were asked whether the meaning of *neutral* in the new sentence was the same as in any of the previous ones, and to elaborate.

Jasien (2010) claims all students correctly identified the colloquial meaning of *neutral* in sentence 2 as either “unbiased”, “not reacting to events” or “doesn’t participate”. However, the latter two are incorrect interpretations of *neutral* in this context and do not correspond with dictionary definitions. The Collins online dictionary (Collins, 2016) defines *neutral* in the context of sentence 2 as “not siding with any party to a war or dispute”. This illustrates how easily imprecise language usage occurs, leading to confusion and incorrect interpretations. A common misinterpretation of the chemical meaning of *neutral* identified by students was “unreactive”. Jasien (2010) ascribes this to the close relationship between chemical and colloquial meanings. This misinterpretation is potentially flawed, based on the incorrect acceptance of “not reacting to events” and “doesn’t participate” as correct colloquial meanings for *neutral*.

Schmidt (1991) regards *neutral* and *neutralisation* as language acting as a “hidden persuader”. When the correct amount of acid is added to a base the solution is referred to as “neutralised” and a “neutral” solution is neither acidic or basic. The implication is that acids and bases are “opposites” and a neutral chemical has neither acidic or basic properties (Taber, 2014). Water, a “neutral” substance however, is able to act as an acid or a base depending on the conditions. “Neutral”, therefore, is confusing because of its dual meaning and its scientific contextual uses. Taber (2014) develops this with examples of “particle”, “electron spin” and associated terms “spin up, ↑, spin down, ↓” which reinforce learners’ understanding of atoms and sub-atomic particles as like small grains or tiny specks of matter. Harrison and Treagust (1996) reported that students believed an electron shell is some form of protective coating of an atom, reflecting associations with the everyday meaning such as *egg shell*. These ideas link with Sutton (1992) who noted the labels given to words affect conceptual interpretation.

2.5 The association between language comprehension and achievement in chemistry

Language comprehension ability correlates strongly with student achievement on chemistry courses (Glover et al., 1991; Bunce and Hutchinson, 1993; Lewis and Lewis, 2007, 2008; Pyburn, Pazicni, Benassi, & Tappin, 2013). Lewis and Lewis (2007), for example, analysed results obtained by 3000 college first year University general chemistry students. They established Scholastic Aptitude Test (SAT[3]) 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. Pyburn et al. (2013) state:

"*...efforts to prepare students for success in general chemistry should include both content and the development of language comprehension skill".* (p. 865)

These studies indicate some significant issues but do not provide substantive insight into the underlying students' learning processes and development of meaning. The question arises as to what is meant by "language comprehension skill" and how this

[3] The Scholastic Aptitude Test is a standardised test generally required for University entrance in the USA. It assesses mathematics, critical reading and writing.

may differ in a scientific context to different subjects. It is important to determine the most problematic language areas and the most effective strategies to achieve significant learning gains.

In addition, as Song and Carheden (2014) recognise:

"*These quantitative studies used SAT scores to measure language comprehension, rather than measures of specific chemistry language comprehension*" (p. 129).

This study involves development of a specific chemistry language diagnostic test which will investigate development in student understanding of chemical language.

Markic and Childs (2016) also identify the importance of linguistic skills and state:

"the promotion of linguistic skills is one of the key objectives of chemistry teaching. It is and should be one of the central aims of teaching and learning in chemistry education."

To support students' language development, chemistry educators' require knowledge and skill to design courses that incorporate these aspects successfully. However, Markic (2015) describes teachers that do not see their role as science teachers in also teaching language.

2.6 Telling the Scientific Story

The "scientific story" is a mechanism of communication and enhancing understanding chemistry language. Science educators including: Mortimer & Scott (2003), Ogborn, Kress, Martins, & McGillicuddy, (1996) and Sutton (1992) emphasise this. Sutton (1992) states that words are involved in transformation of thought, so lessons should be designed based on an interpretive view of the role language plays in science; with regard for people's varied understandings (Section 2.3 p. 38). Sutton's 'scientific story' describes people behind concepts contributing to our understanding of scientific phenomena over time and how this is reflected in words ascribed to observed phenomena. Sutton's philosophy extends beyond considering word origins and meanings to historical development of scientific ideas.

Ogborn et al. (1996) argue that scientific stories generate interest in topics with which students struggle to engage. For example, Ogborn et al. (1996) cite the story of French-

Canadian fur trapper Alexis St Martin whose accidental gunshot wound exposed the interior of his stomach, providing his doctor, William Beaumont, with an opportunity to study digestion directly over a protracted period of time. The story is a mechanism to engage interest but the question arises as to whether it develops student understanding. It may be regarded as irrelevant information from a learning perspective. If Sutton's model was followed, a teacher may produce the doctor's original findings, asking students to draw conclusions and consider recent developments. This may provide a more valuable learning experience.

Mortimer and Scott (2003) refer to the 'scientific story' as an account of familiar natural phenomena. In their model, the teacher's role is to design a series of staged lessons that 'build up' the story (p. 47). The teacher requires awareness of students' existing and developing understandings, using these to build convincing lines of argument that guide them towards the accepted scientific viewpoint. The authors use "rusting" as an example. Rather than the usual experiment of placing iron nails in varying conditions in test tubes, the teacher provided students with an iron nail, instructing them to place it where they thought rust would form. This activity starts the "scientific story", stimulating interest and proposals for places where nails might rust. After three weeks students brought their nails back to the laboratory, and mounted each on card with a description of the conditions to which their nail had been exposed. A display was created presenting the nails sequentially from least to most rusty. Students compared the conditions to find out which created the most rust, stimulating discussion. Next, rust-creating conditions were reviewed, identifying factors present in all cases. At this stage, specific terminology such as *moisture, salt, cold* was introduced to refine ideas. Finally, students continued the story by designing and carrying out a confirmatory test tube experiment that concludes with identification of conditions required for rusting to occur.

This sequence does not involve a historical perspective, describing prior ideas about causes of rusting but is a heuristic approach as advocated by Armstrong (1925). Crawford, Kelly & Brown (2000) report a similar strategy by a teacher in an elementary school in California who sought to develop students' experimental ideas in relation to marine animals in a classroom aquarium. The strategy adapts Sutton's interpretive role for language and Carlsen's (2007) view of achieving shared understanding (Section 2.3 p. 38).

A fourth version is an adaptation or extension of Sutton's proposals. Sutton identifies value in understanding the origins of scientific words as these reveal how scientific ideas develop over time. However, the example of capillary attraction (Faraday, 1861) shows how scientific words do not necessarily reflect current understanding of a phenomenon. In this example, the word *capillary* was assigned because the phenomenon was observed in capillary tubes. This does not indicate scientists' understanding of *capillary* at the time. Knowledge of the origin of *capillary* removes its arbitrary nature and enables correct association with blood capillary. Emphasis should be placed on origins of scientific words when teaching science. This strategy is advocated by Herron (1996) who states

"*Discussion of word histories can add a human touch to the teaching of science as well as improve the student's understanding of science and help students develop word-attack skills*[4]*"* (p. 176)

Benzene is an example. When this term is introduced in organic chemistry it is often associated with scientific stories. Firstly, the well-known 'structural' scientific story: in 1865, Kekulé (1865) described the structure of benzene as a six-membered carbon ring with alternating single and double bonds. Later in his life, he related the story that this structure had come to him in a dream in the form of a snake biting its own tail (Figure 2.6).

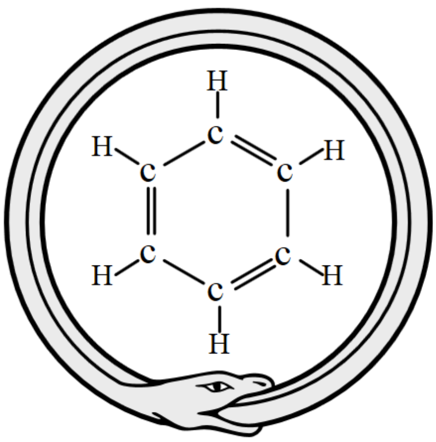


Figure 2.6 The Ouroboros – Kekulé's visualisation of the structure of benzene (Haltopub, 2013)

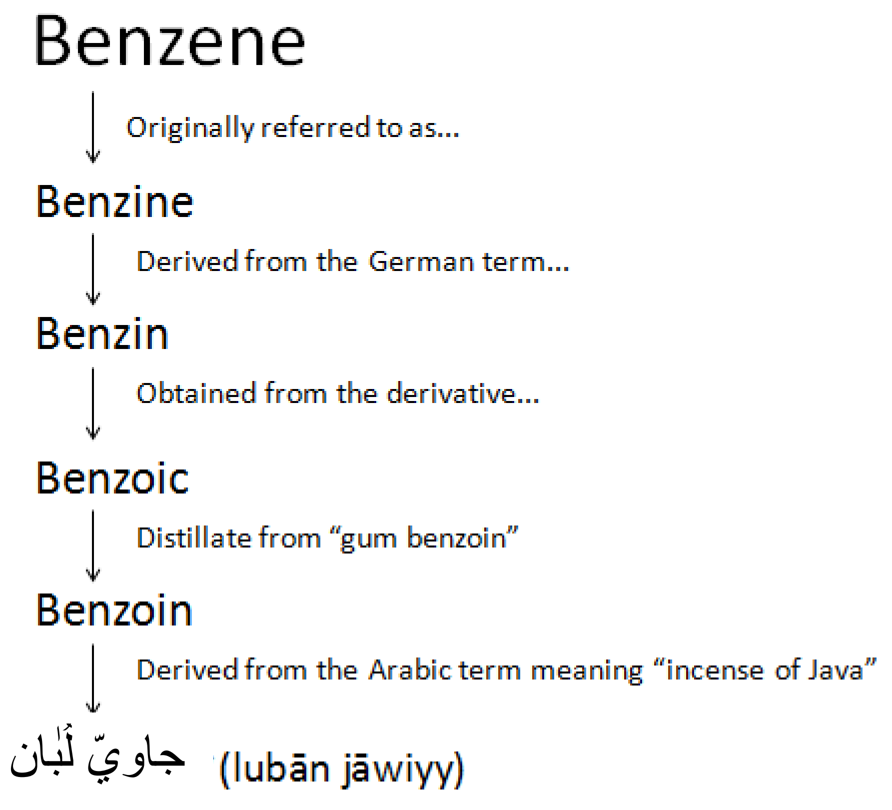
[2] Word attack skills refers to developing the reading skill of recognising new words formed by adding prefixes and suffixes to root words.

This ancient symbol known as the "Ouroboros" signifies cyclicality, something regenerating itself, and is frequently used in Alchemy (Read, 1957). This structural story provides students with a visual representation of the ring structure, enabling appreciation of the development of understanding of benzene chemical structure.

Secondly, the 'structural-reactivity' story describes development of an explanation for benzene's low reactivity despite structural evidence suggesting the molecule includes three carbon-carbon double bonds. This story is an important part of A-Level[5] chemistry (Gent and Ritchie, 2010).

A third story describes the origins of the word *benzene*. The suffix "-ene" and the presence of carbon-carbon double bonds implies an alkene, leading logically to a systematic name of "cyclohex-1-3-5-triene". The origin of *benz-* requires explanation. Box 6 traces the origins of *benzin* back to its Arabic roots (Harper, 2016). By recounting this story, *benzene* as a word is transformed from an arbitrary, functional chemical to a substance with origins grounded in two thousand years of history.

Box 6 *The etymology of "benzene"*



[5] "A-Level" is a UK qualification for post 16 year olds.

This etymological scientific story evokes images of medieval era traders exchanging incense as an exotic and valuable substance. The story provides opportunities to demonstrate chemistry's historical and cultural origins, with opportunities to establish connections to other chemical terms, such as *organic* as a term for a substance originating from a plant. A bottle of benzoin essential oil shown to students makes *aromatic chemistry* accessible. Links to perfume and cosmetics manufacture are possible, as well as perceptions of chemists heating up this curious substance to gain better understanding. Modern linguistic links to *benzin* (German for "petrol") leads to discussion of benzene in fuels. Etymological connections to other organic solvents including phenol and toluene can then be established. The use of scientific stories provides opportunities to link language to culture (Mamlok-Naaman, Abels & Markic, 2015) and engage with culturally diverse classes (Markic and Childs, 2016).

This section has explored how words create "scientific stories" and how these may be used to enhance subject understanding. In particular, consideration has been given to the value of words as interpretative tools rather than simply labels for substances or processes in chemistry. Next, I consider relevant theoretical frameworks.

2.7 Theoretical Frameworks

Social constructivism and learner progressions are discussed as supporting frameworks.

2.7.1 Social Constructivism

Constructivism is a theory of learning rather than a description of teaching (Fosnot and Perry, 2005). It 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 his

"...earlier model had proved insufficient and that his central new idea is that knowledge proceeds neither solely from the experience of objects nor from an innate programming performed in the subject but from successive constructions". (p. 5)

Piaget's ideas were based on his early work as a biologist studying biological adaptation in snails. He suggests 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) or, as Byrne, Johnstone and Pope (1994) state, "*difficulty with language causes difficulty with reasoning*". This implies 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 (Glaserfeld, 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, 2005). Vygotsky referred to the interface where a child's spontaneous concepts meets the teacher's scientific concepts as the *zone of proximal development* (ZPD – represented in Figure 2.7) defining it as

"*…the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers.*" (Vygotsky, 1978, p.86)

Vygotsky's work represents a significant shift in moving education from knowledge transmission towards knowledge construction. Vygotsky argued that tests showing what a student could do unaided were less useful than assessments of what could be achieved with limited support. 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.

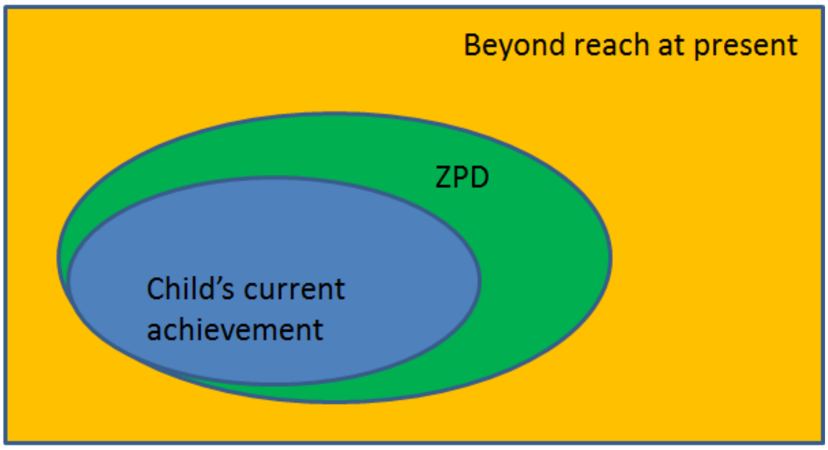


Figure 2.7 A representation of the Zone of Proximal Development (ZPD) in relation to a child's current achievement (Atherton, 2013)

2.7.2 Learning progressions

Learning progressions are descriptions of increasingly sophisticated ways of thinking about a topic (National Research Council, 2007). Corcoran, Mosher and Rogat (2009) describe them as:

"*…empirically grounded and testable hypotheses about how students' understanding of, and ability to use, core scientific concepts and explanations and related scientific practices grow and become more sophisticated over time, with appropriate instruction*" (p. 8).

Gotwals and Alonzo (2012) suggest learning progressions can be used to collate previous work coherently and systematically and to design a "bottom up" approach that accounts for *how* students learn topics and not only *what* should be learned. In effect, learning progressions combine curriculum and learning theory.

Substantial research effort has mapped cognitive growth as a student learns about concepts such as force and motion (Ausubel, 1963; Bruner, 1966). This examines the learning path as a student, over time, moves from "novice" to "expert" (Edwards and Mercer, 1987). Steedle and Shavelson (2009), for example, provide a linear progression map of student understanding of force and motion in relation to explaining constant speed. The progression describes what students know and can do when confronted with force and motion phenomena, mapping a cognitive progression for "understanding" force and motion.

The production of such linear progressions are an attempt to provide an order and logical development from one stage to the next that may be unrealistic. In addition, there is no reference to "wrong turns" and "blind alleys" within this progression. That is to say, situations where students find they have developed misconceptions that prevent them from progressing and how can these be addresssed. Shavelson and Kurpius (2012) question whether such a learning progression reflects cognition accurately, as a student's knowledge may not be so orderly. A student may have loosely related knowledge obtained from personal experiences and brief classroom encounters, meaning progress from novice to expert may be context specific, hectic and non-linear. In addressing a new problem, depending on the context, students may access differing memory networks. Shavelson and Kurpius (2012) state that progressions are not inevitable but depend on instruction interacting with students' prior knowledge and new knowledge construction, placing their work within the constructivist paradigm. This is significant in relation to the non-traditional students at the Foundation Centre. They have a very wide range of previous knowledge and experience and are, consequently, at very different points on their learning progression.

Gunckel, Mohan, Covitt and Anderson (2012) pursue a sophisticated approach which focuses on language use developments in relation to environmental literacy learning progression frameworks. They explored scenarios such as "*After it rains you notice puddles in the middle of the soccer field. After a few days you notice that the puddles are gone. Where did the water go*?" and "*What happens to salt when it dissolves in water?*" These scenarios inspired the scientific scenarios used in this study (Chapter 4, Section 4.11.1, p. 129). Gunckel et al. (2012) emphasise the importance of Discourse, identifying primary and secondary Discourses described by Gee (1991). Primary Discourse is the language associated with communicating with family. Secondary Discourses develop as people expand their communities of participation with institutions such as schools, workplaces or universities. This is synonymous with Lemke's ideas of colloquial and scientific language (Lemke 1990; Section 2.3, p. 38). Students' primary discourses define the lower end of their learning progression framework. The process of learning involves mastering talking, thinking and acting associated with secondary Discourses. In this thesis, these transitions are explored from Year 0 into undergraduate study. Their development of secondary Discourse required to engage successfully within the discipline specific community is investigated.

Gunkel et al. (2012) analysed their student responses using force-dynamic and model-based reasoning (Givón, 1998 and Pinker, 2007). These two authors argue that there is a "theory of the world" built into the basic grammar of all languages that shapes how we view and explain events (force-dynamic reasoning). Relevant to a diverse international cohort, Pinker (2007) notes that how students make sense of the world is rooted in the grammatical structure of the language of their primary home discourse. Model-based reasoning is scientifically based and recognises that phenomena occur within connected and dynamic systems operating on multiple scales, constrained by fundamental scientific principles. By searching for characteristics of force-dynamic and model-based reasoning, Gunkel et al. (2012) identified features in student responses that changed from less to more sophisticated answers. The least sophisticated responses (level 1) were force-dynamic dominated accounts. For example, "*it got dried up by the Sun*" (puddle); "*the water overpowers the salt by making it disappear*" (salt). In contrast, sophisticated responses (level 4) were qualitative model-based accounts. Students used scientific principles that connected phenomena on macroscopic and sub-microscopic scales. For example, sophisticated responses to the puddle scenario describe water moving along multiple pathways such as into the groundwater supply and evaporation. Level 4 responses to the dissolving scenario discuss salt breaking up into Na^+ and Cl^- ions. Thus, language analysis focuses on quality of responses in terms of appropriateness and accuracy of the language usage.

Gunckel et al. (2012) established that many of their American students used scientific "names" for systems and processes that exceeded their ability to construct an explanation using scientific principles. Some students, however, showed appreciation of scientific principles but did not know the appropriate scientific language. Based on these observations Gunckel et al. (2012) developed two alternative pathways through the learning progression. The "structures-first" route focused on naming while the "principles-first" track focused on explaining with principles. Both lead to level 4 which requires combining these two aspects to produce meaningful explanations. The suggestion is that both routes are acceptable but it may be that one route is more successful than another. In particular, as language usage gets more technical it may become increasingly difficult for a student to follow a "principles first" track because it is impossible to understand and explain the principles without the scientific language.

2.8 Implications for teaching practice in Higher Education

The depiction of Michael Faraday delivering his lectures at the Royal Institution by Alexander Blaikley (1855, Figure 1, p. 27) shows a diverse crowd of women, children and men (including royalty) packed into the auditorium listening intently and enthusiastically to his account of the latest scientific developments. Over 160 years later, the didactic lecture remains the dominant mode of delivery in UK Higher Education (Byers and Eilks, 2009; Lancaster, 2013).

However, the emergence of constructivism as a learning theory has led to significant developments in educational practice to incorporate an active learning environment in classrooms and lecture halls. Applefield, Huber and Moallem (2000), for example, argue that the constructivist approach to teaching emphasises a top-down view of instruction. Students are intentionally confronted with complex tasks that can only be completed under teachers' guidance, creating a need to develop relevant skills to complete them. Tasks must be carefully constructed to operate within students' ZPDs in an atmosphere of cooperative learning. Applefield, Huber and Moallem, (2000) and Fosnot and Perry (2005) state that

"*Teachers need to allow learners to raise their own questions, generate their own hypotheses and models as possibilities, test them out for viability and defend and discuss them in communities of discourse and practice*." (Applefield, Huber and Moallem, 2000, p. 51)

The teacher is challenged to show awareness of students' current understanding, designing strategies that enable movement into their ZPDs effectively. The "scientific story" of rusting (Section 2.6, p. 56) illustrates a constructivist approach through an extended learning activity. Taber (2002) discusses the challenges of scaffolding learning (p. 67) within the ZPD and the use of tasks such as Directed Activities related to Text (DART); an activity incorporated into the teaching strategies (Chapter 3, Section 3.3.11 p. 98). In Higher Education the challenge is to apply constructivist learning theory within the parameters of lecture style delivery to large numbers of students. An approach that has gained momentum is the "flipped lecture" (Bergman & Sams, 2012; Flynn, 2015; Lancaster, 2013; Seery 2015). In this model, learners are presented with material (content) in advance of the class to enable active learning strategies during formal lesson time. This strategy has been specifically defined by the Flipped Learning Network (2014) as:

"...a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter." (no page number assigned)

Providing materials in advance of chemistry lectures and recommended reading is well established (Kristine, 1985; Collard, Girardot & Deutsch 2002). However, flipped learning aims to fundamentally change the "lecture" from a passive to an active learning experience. Additionally, rather being a single intervention, it is a significant holistic pedagogical change to curriculum delivery (Seery and McDonnell, 2013).

Flipped learning can involve a range of approaches (Seery, 2015) but the predominant format is production of narrated powerpoint recordings known as screencasts (Read and Lancaster, 2012). Although a recording may vary in length from 5 – 30 minutes it requires between 3 and 10 times as long to produce (Flynn, 2015). Students like being able to access the material in their own time and replay content (Seery, 2015). This may reduce cognitive load and improve learning (Abeysekera & Dawson, 2015). Students for whom English is not their first language adopt screencasts quickly (Lancaster, 2013), most likely for this reason. These materials provide students with opportunities to improve their understanding of subject specific language prior to a lesson. Therefore, it is likely that they will engage meaningfully in the lesson activities, including, for example, peer instruction (Schell and Mazur, 2015). These authors use flipped learning to enable students to prepare material prior to lectures. A mini-lecture on a concept is followed by a conceptual question such as:

"Spontaneous reactions occur:
(A) Instantly
(B) Slowly
(C) Both (A) and (B)" (Schell and Mazur, 2015, p. 331)

Responses are obtained via individual student response systems or "clickers". Students discuss with peers before answering again. From a social constructivist perspective, these discussions allow students to develop understanding of the concept. From a language perspective, this specific question tests student understanding of the dual meaning word *spontaneous* in relation to a chemical reaction compared to an everyday context. *Spontaneous* was a problematic term identified in the chemical language studies as described earlier in Table 2.4 (p. 51).

This approach raises considerations from a language perspective. Content delivery is front loaded into pre-class screencasts. Authors of the materials report a significant time investment in doing this. The question arises as to whether this is because careful consideration is given to choice of words and explanations provided in these resources. Well prepared resources may use a written script in which language usage is succinct and precise. Therefore, the resource is useful as the students can access this as often as they like and the quality of explanations and the language used may be superior to the free running delivery in a live lecture. Conversely, a poorly constructed screencast may be less useful, as unclear language is not clarified as it may be in a live lecture. Also, these materials reduce student exposure to wider discourse cues such as gestures and facial expressions that help make sense of language (Carlsen, 2007, p. 61). Studies of flipped learning focus on active learning strategies utilised (Seery, 2015) but careful consideration must be given to linguistic demand of pre-class materials to ensure they are accessible to all students.

2.9 Eye tracking studies

Eye tracking software is used to track human visual attention based on the eye-mind assumption (Just and Carpenter, 1980). This assumes that attention relates to eye fixation location and duration as an indication of attention and processing difficulty. In this study, eye tracking was used to investigate students' reading of chemistry text. Eye tracking has been applied to reading (Paulson & Jenry, 2002; Rayner, Chace, Slattery, & Ashby, 2006). Rayner et al. (2006) describe how reading comprises three components, namely saccades, fixations and regressions. Saccades are rapid movements that move the eye from one place to the next. Skilled readers typically move about seven to nine letter spaces with each saccade. Saccades are separated by pauses known as fixations; typically lasting 200-250 msec. During the fixation new information is encoded. Regressions refer to a saccade that moves the eye backward in text to read material previously encountered. When readers encounter difficult words or syntactically complex sentences fixations lengthen, saccades shorten and more regressions occur (Rayner et al., 2006). Fixation locations and duration reflect individual reading strategies and prior knowledge (Hyönä, Lorch, & Kaakinen, 2002). Tsai, Hou, Lai, Liu & Yang (2011) examined student problem solving in a study involving six 19-21 year old earth science students. They identified that "successful" problem solvers spent more time on the relevant factors in relation to the problem compared to those who were unsuccessful. Difficulties decoding the problem, identifying relevant factors and regulating concentration were identified among the unsuccessful solvers. The eye tracker system places students in an unnatural situation and may not be recording reading patterns in a more relaxed setting. This may exaggerate the differences between students depending upon how they respond to the experimental situation. However, these studies demonstrate potential for eye tracking to reveal students' eye movements and their reading strategies. This is unique data that could not be obtained any other way. This study will use eye tracking to investigate students' reading of chemistry text for students with different levels of chemical language understanding.

2.10 Second language learning theories

There are four reasons why second language learning theories are relevant to learning chemistry in the context of this study. Firstly, Vygotsky (1962) likened learning scientific concepts from spontaneous concepts to learning a second language and the interaction with native language:

"*The influence of scientific concepts on the mental development of the child is analogous to the effect of learning a foreign language, a process which is conscious and deliberate from the start. In one's native language, the primitive aspects of speech are acquired before the more complex ones. The latter presupposes some awareness of the phonetic, grammatical and syntactic forms. With a foreign language, the higher forms develop before spontaneous, fluent speech [...] It is not surprising that an analogy should exist between the interaction between the native and the foreign language and the interaction of scientific and spontaneous concepts, since both belong in the sphere of developing verbal thought".* (p. 109)

Vygotsky suggests that learning a foreign language involves interaction with the native language just as the acquisition of scientific concepts (those obtained through schooling) have an interaction with spontaneous concepts acquired from a child's experience. There are similarities here with Lemke's ideas of the interaction between scientific and colloquial language (Lemke, 1990; Section 2.3, p. 38)

Secondly, teaching from a social constructivist viewpoint emphasises the importance of student discourse and providing opportunities for students to discuss and develop understanding (Section 2.7.1, p. 60). Second language learning research has increasingly emphasised the social dimension (Firth and Wagner, 2007) and could, therefore, provide insights into student learning in this context. Thirdly, there are many parallels between potential undergraduates learning chemistry and second language learners. For example, native language acquisition takes place in childhood whereas second language learning often takes place as an adult. All Foundation Centre students are adults, therefore, factors that have a significant effect on success in second language learning may also be relevant to learning chemistry in non-traditional students. Spolsky's (1989) general model of second language learning addresses this area (Section 2.10.1). Lastly, a substantive area of second language learning research has explored the notion of "interlanguage" (Selinker, 1972) as transitionary language systems when learning a new language. The existence of interlanguage in science has been explored by Rincke (2011) in science education. This theory is discussed in Section 2.10.2.

2.10.1 Factors affecting second language learning

Spolsky's (1989) proposed a general model of second language learning. He developed a mathematical formula to represent the significant factors involved as follows:

"$K_f = K_p + A + M + O$" (p. 15)

Where "K_f" is future knowledge and skills, "K_p" is current knowledge and skills, "A" is various components of ability (including physiological, biological, intellectual and cognitive skills), "M" is affective factors (such as personality, attitudes, motivation and anxiety) and "O" represents opportunity for learning the language (consisting of time multiplied by type i.e. formal and informal learning). Each factor makes a difference to the result and if any are absent then there will be no learning. Mathematically, therefore, these factors may be better represented as multiples rather than additions so that if a factor was zero then the overall value would be zero. Spolsky describes 74 "Conditions" which make language learning success more or less likely based on his interpretation of empirical language learning studies.

Some of these conditions are "necessary", without which learning is impossible; many are "graded" conditions in that there is a relationship between the extent to which a condition is met and the nature of the outcome; others are" typicality" conditions that apply typically but not necessarily.

Table 2.6 provides examples of a number of these conditions that could be important to the chemistry learning context. For example, the "opportunity for matching" condition describes the importance of providing opportunities for learners to match their knowledge to native speakers. Beyond the classroom, chemistry learners may have limited opportunities to experience "native chemistry" speakers, indicating the importance of informal learning opportunities to increase chemical language exposure.

Figure 2.8 is a schematic representation of the interplay between the factors Spolsky believed were most significant for learning. Each box represents clusters of different conditions. Arrows connecting boxes show directions of influence. Social context makes up the first cluster of conditions.

These conditions influence the learner's attitudes towards the community speaking the target language and towards the learning situation (Gardner, 1979). These two kinds of attitude, according to Spolsky and based on the work of Gardner and Lambert (1959), lead to the development of motivation on the part of the learner.

Condition	Grading[1]	Explanation
Discrete Item	Necessary	Knowing a language involves knowing a number of the discrete structural items (sounds, words, structures etc.) that make it up.
Productive /Receptive skills	Necessary, graded	Individual language learners vary in their productive and receptive skills.
Opportunity for Matching	Necessary, graded	Learning a language involves an opportunity for the learner to match his or her own knowledge with that of native speakers or other targets.
Language Distance	Necessary, graded	The closer two languages are to each other genetically and typologically, the quicker a speaker of one will learn the other.
Native speaker target	Typical, graded	Second language learner language aims to approximate native speaker language.
Abstract Skills	Typical, graded	Formal classroom learning of a second language is favoured by the development of abstraction and analysis.
Child's Dependence	Typical, graded	The social situation faced by a child in a second language environment favours second language learning.
Second language learning anxiety	Typical, graded	Some learners develop levels of anxiety in learning and using a second language that interfere with the learning.
Linguistic Convergence	Typical, graded	Prefer to learn a language when: (a) you desire the social approval of its speakers, and/or (b) you see strong value in being able to communicate with its speakers and/or (c) there are no social norms providing other methods of communicating with speakers of that language, and/or (d) your learning is reinforced or encouraged by speakers of the language.
Motivation	Typical, graded	The more motivation a learner has, the more time he or she will spend learning an aspect of a second language.
Attitude	Typical, graded	A learner's attitudes affect the development of motivation.
Formal language learning – teaching	Typical, graded	In formal language learning situations, multiple opportunities to observe and practise the new language can be provided. The more these match other relevant conditions (the learner, the goals), the more efficient the learning.

[1]See text for a description of the different categories of condition.

Table 2.6 Conditions for second language learning (Spolsky, 1989)

Motivation is a predictor of the amount of time a learner would apply to language learning (Carroll, 1962). The recognition of the importance of social context influencing attitude which, in turn, determines motivation is a strength of this model. There is much discussion and recognition of the importance of motivation, particularly for non-traditional learners (Bye, Pushkar & Conway, 2007). In seeking the drivers for motivation, Spolsky's model guides us to consider students' attitudes and their social context. Non-traditional students often come from communities with low participation in Higher Education (Bowl, 2001) and social context can have an important influence.

The second influence of the social context is provision of formal and informal situations. Formal opportunities refer to the specific institutionalised provision whilst informal opportunities refer to wider instances for interaction with the target language. Students coming from different social backgrounds will have had different informal opportunities to interact with chemical language. Non-traditional students, working full-time for example, may have had limited opportunity to interact with the target chemical language.

The second cluster comprises the capabilities and knowledge and experience the learner brings. Spolsky states

"*Of particular importance among the personal learner characteristics are previous knowledge; language learning aptitude; learning style and strategies; and personality factors, of which anxiety is the most clearly relevant. The combination of these factors accounts for the use the learner makes, consciously or unconsciously, of the socially provided formal or informal learning opportunities*" (p. 27)

Anxiety is a significant issue for non-traditional students returning to university and can have an important influence over the students' use of the learning opportunities with which they are presented.

The central cluster of age, personality, capability and previous knowledge are also highly applicable to non-traditional students. The diverse nature of the cohort means that there is a wide variability in all of these conditions.

The final outcome of second language learning is typified by incomplete success if the aim is to adopt native speaker usage. Some learners appear to stabilise as users of an alternative language system regardless of how actively they continue to use their second language (Miles, Mitchell and Marsden, 2013). This phenomenon has been referred to as "fossilisation" (Selinker, 1972; Han and Selinker, 2005). Psycholinguistic and sociolinguistic explanations have been proposed. Psycholinguistic explanations suggest that the learning mechanisms available may cease to work, to some extent, for adult learners. This is known as the Critical Period Hypothesis as first proposed by Lennenberg (1967). Sociolinguistic explanations state that older L2 learners do not have the social opportunities, or the motivation, to identify completely with the native speaker community (Miles, Mitchell and Marsden, 2013).

Spolsky's general model is, in effect, a metastudy that comprehensively brings together a wide array of factors that can influence learner success and illustrates the complexity of the situation. With seventy four different conditions affecting learner success the impact of changes to improve one or two of these conditions may be negligible or cancelled out if a different condition worsens chances of success. The grading of the conditions is an attempt to provide some indication of the relative importance of these conditions but more work is required to understand this in specific learning contexts.

Although Spolsky's model is useful for consideration of factors influencing success in the individual learner it is not a cognitive theory that seeks to explain how learners process and acquire language. For this, I consider the second language learning theory of "interlanguage".

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Figure 2.8 Spolsky’s general model of second language learning (Spolsky, 1989, p. 28)

2.10.2 Interlanguage

Selinker (1972) proposed "interlanguage" to refer to language produced by learners as a succession of transitionary systems that take the learner nearer to the target language, identifiable as resulting from systematic rules. It continues to be a useful descriptive term in second language learning research (Selinker and Gass, 2008). Learners can produce systematic utterances whether or not they are native-like. The interlanguage concept "*relies on two fundamental notions: the language produced by the learner is a system in its own right, obeying its own rules, and it is a dynamic system, evolving over time*". (Mitchell, Myles and Marsden, 2013, p. 36).

Corder (1967) was the first to focus attention on learner errors as an independent linguistic system worthy of description. Error analysis studies (Richards, 1974) indicated that the majority of errors could not be traced to the native (L1) language, so errors must originate internally from the learner (Mitchell, Myles and Marsden, 2013). An example of systematicity in learner language is in the common developmental sequences followed by learners from different native language backgrounds acquiring linguistic structures such as questions or negation in English or German. Tarone and Swierzbin (2009) describe how learners with different native languages produce questions with identical structures. They began a question with a question word like "why" or "what" followed by a subject/verb/object, for example:

"What he is doing?"
"Why this guy say, stop?"
"Why the bus driver can't stop for him?" (p. 46)

This structure is uncharacteristic of native English speakers and does not appear in English grammar books. Therefore, it is a unique utterance generated by the learner.

Selinker (1972) highlights "backsliding" as characteristic of interlanguage. This means reappearance of linguistic phenomena previously thought to have been eradicated. This phenomenon was noticeable when the learner was presented with challenging subject matter or in a state of anxiety. Rincke (2011) refers to backsliding in a carefully designed and detailed study of 47 secondary school (average age 14) students' conceptual understanding of mechanics. His aim was to investigate the occurrence of language learning processes such as interlanguage when students were developing scientific explanations of scenarios involving *force*. Lessons were audio and videotaped and transcribed with analysis undertaken on a sub-set of 20 students that had contributed most significantly to the class discussions. Consequently, the study focused on the most vocal and confident students whereas the least confident students were likely to be those with the greatest language issues.

Rincke (2011) designed a series of mechanics lessons that differentiated everyday and scientific usage; the scientific usage of *force* denoting at least two partners involved in an interaction was explained. Mixing everyday and scientific usage of *force* was avoided. Rincke engaged students in meta-discourse (Lemke, 1990) involving participation in discussions about language, including syntactic and semantic features of informal everyday and formal scientific uses of *force*. His analysis reveals students experienced difficulty adopting scientific use of key terms, despite their teacher's exemplification and explicit guidance. For example, one student suggests

"*One person exerts a force on the ball and throws it to another person. The other person catches the exerted ball. The other person exerts a force on the ball and throws it back. The exerted balls are thrown back and forth"* (Rincke, 2011, p. 247).

Rincke (2011) identifies the student is testing the phrase *to exert a force* and has produced the phrase "exerted ball", utilising *exerted* in adjectival form. He suggests the student is concentrating on the pattern given by the teacher with little regard to content. However, *exerted ball* was not used by the teacher, so this appears to be unique student generated interlanguage based on linguistic input. The student does not understand the verb *to exert* correctly so is exploring its application in a transitional state. This proved significant in relation to analysis of student interviews (Chapter 6) for developing usage of scientific terminology.

Rincke (2011) observed that early on in the teaching sequence students demonstrating scientific understanding of force but in more complex scenarios, later in the teaching sequence, students reverted to everyday language. Rincke (2011) interpreted this as evidence of "backsliding" within a scientific interlanguage. In addition, students rarely used the phrase "*an object exerts a force on another object*" throughout the teaching sequence despite this being emphasized in the teaching. The exposure of students to this phrase may have been insufficient for it to become embedded and used spontaneously. Alternatively, scaffolding of learning may have been poor. The students are unlikely to use the phrase outside the science classroom. Therefore, Spolsky's Condition of Child's Dependence (Table 2.6, p. 70) may be significant, as students' social situations and chances of successfully acquiring the target language are reduced by limited exposure and usage. This highlights that informal learning is important, as this affords opportunities for students to experience and use scientific language in context.

Olander & Ingerman (2011) investigated interlanguage in relation to 17 year old Swedish students' discussion of evolution. They studied 48 students in two classes undertaking discussions of their ideas about evolution. Twenty-nine students were videotaped. Their discussions were classified into sequences that exhibited colloquial, inter- or school science language. The researchers identified three prominent conceptual notions in students' discussion. These were *randomness*, *need* and *development*. The students alternated between the three language types but as student discussions progressed, they developed school science explanations. Colloquial language was not considered problematic but by discursive negotiation the students moved towards a scientific explanation for evolution. The authors also discuss that in Swedish, the words *development* and *evolution* are synonyms. *Development*, (*utveckling* - Swedish) has other contextual uses, such as growth, and in thermodynamics. Thus, *utveckling* is confusing, with multiple contextual meanings. This demonstrates that international students may mis-interpret words unexpectedly due to everyday usages in their native language.

2.11 The use of corpora in language teaching

A corpus is a collection of authentic language, either written or spoken, which has been compiled for a particular purpose (Sinclair, 1991). A corpus is assembled according to explicit design criteria to be representative of a particular language or genre (Flowerdew, 2012). Corpora have been assembled such as the British National Corpus (2016) or the Corpus of Contemporary American English (2016). 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. Experienced readers appreciate that words are situated, so analyse a whole sentence before determining meaning of a specific word. Therefore, corpora providing multiple examples of contextual usage of subject-specific language are potentially valuable as language-learning aids. The unique corpus assembled for this project (Chapter 3, Section 3.1, p. 81) is described in Rees, Bruce & Bradley (2013) and Bruce, Coffer, Rees & Robson (2016).

2.11.1 Data driven learning

The corpus (Chapter 3, Section 3.1, p. 81) prompted development of "data driven learning" (DDL) strategies to support students' chemical language learning. Johns (1991) uses the term DDL 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).

DDL prompts the learner to use data to uncover rules behind language, while the teacher "*provides a context in which the learner can develop strategies for discovery*" (Johns, 1991, p. 1).

After several years utilizing concordance output (the search results) from corpora with students, Johns (1991) concluded that concordance output is useful for learners to identify patterns and generalizations in the target language, and places learners' personal grammar discoveries at the centre of language learning. This results in a shift of emphasis from the teacher as imparting knowledge to facilitating and guiding the student discovery process. Through authentic language research, the students develop their language understanding. This is a constructivist approach (Section 2.7.1, p. 60). This viewpoint is supported by Bernadini (2004), who explains that corpora provide ideal opportunities to observe what and how language is spoken typically. The corpus shortcuts language learning by providing repeated experiences of language instances. Aston (1995) similarly points out that concordances highlight patterns of textual repetition and variation. Mudraya (2006) utilized DDL with engineering students to develop understanding of scientific and non-technical vocabulary. In particular she discusses different contextual uses of *solution,* and uses data to illustrate language structures observed in two contexts. She outlines activities for students but does not explore the impact on student learning.

Johns (1991) uses a three step process of "Identify-Classify-Generalise" when designing DDL activities. The first step is to identify the structure or words to be investigated. This may be student- or teacher-led. Classifying is necessary so students do not become overwhelmed by large data sets. Generalising is the process of constructing the rules for the use of the structure or words based on the evidence. Johns (1991) demonstrates this by exploring differences between the meanings for *convince* and *persuade* (Identify). Dictionary definitions show one word used to explain the other, for example,

"*Convince - to persuade (someone) to do something.*

Persuade - to cause to believe; convince." (Collins, 2016)

Using a corpus, students explore multiple examples of how these words are used in authentic language. Johns (1991) describes how students discover that *convince* is followed frequently by "that" whereas *persuade* is followed frequently by "to" (Classify). The data has revealed a difference which requires explanation by the students. By examining the citations in more detail, Johns (1991) states the students suggested the "to" infinitive is typically associated with actions *i.e.* we try to *persuade* someone *to do* something. Whereas the "that" clause is associated with truth and that we try to *convince* someone *that* something is the case (Generalise). 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 such as pronouns or infinitives to explain and discuss the observations. Meaning is developed via exemplification from data.

2.12 Conclusion and research objectives

Chemistry educators are required to be highly skilled communicators. They utilise language in multiple forms (*e.g.* written, verbal, symbolic, graphical, mathematical, gestures) to convey knowledge and develop understanding in students. The work of Gardner (1972) and Cassels and Johnstone (1985) highlighted the problematic nature of many scientific words. Sutton (1992, 1998) argues for greater emphasis on the words of science as interpretative tools and a focus for teaching. Edwards and Mercer (1987), Lemke (1990) Mortimer and Scott (2003), Ogborn et al. (1996), amongst others, discuss the patterns and complexity of science classroom discourse. Johnstone's chemistry learning triplet (1991) visualises challenges faced by chemistry students. Taber's (2013) revisiting of the triplet emphasises language as an important enabler for students to move between these levels. These are the central themes to the thesis and it is argued that learning chemistry is like learning a second language, particularly in the context of non-traditional students. Therefore, the thesis explores the relevance and utility of the second language learning theories of Spolsky (1989) and Selinker (1972) and the application of corpus linguistics strategies within chemistry teaching. Markic and Childs (2016) acknowledge the importance of language in the chemistry classroom and the need for further research in this area. They identify the value in developing diagnostic tools to assess student linguistic abilities. The development of the chemical language diagnostic test (CLDT) as part of this project is a contribution to this area. The research uses the CLDT to provide data on potential undergraduates' chemical language comprehension ability, how it develops and its impact on outcomes (Research Questions 1 and 2; Chapter1, Section 1.4, p. 24). Markic and Childs (2016) also state that resources need to be developed that focus on developing students' writing and reading skills. The thesis develops a unique corpus of student texts (FOCUS) and investigates its application within a foundation level general chemistry programme utilising data driven learning activities (DDL). Research Question 3 investigates the application of these strategies in the classroom and Research Question 4 investigates the potential undergraduate usage of language based learning strategies. Markic and Childs (2016) recognise the importance developing teachers' pedagogical knowledge in this area. This thesis demonstrates how language based activities can be applied in the chemistry classroom and how second language learning theories can provide insight into student learning in chemistry.

Chapter 3

Designing the teaching activities

Chapter 2 discussed the variety of challenges that chemical language can present students. Johnstone's triplet (Section 2.2.1, p. 33) demonstrates how students are required to move between macroscopic, sub-microscopic and symbolic levels. The variety of vocabulary required to operate within each of these levels was demonstrated in Box 3 (p. 35). The challenges of scientific and non-technical vocabulary were also discussed (Section 2.4, p. 44) and potential value in understanding the roots of words in order to decipher new and unfamiliar vocabulary. With these challenges in mind, the teaching activities were informed by social constructivism (Section 2.7.1, p. 60) and with the aim of applying data driven learning (Section 2.11.1, p. 78) in a chemistry context.

The teaching activities comprised the development of a corpus of university student texts called the Foundation Corpus or FOCUS and novel language focused classroom based activities. The design of both components is described and discussed below. A timeline for the teaching activities is included in Table 4.1 (Chapter 4, p. 100). The development of student chemical language understanding was investigated with a chemical language diagnostic test (CLDT) and student interviews. These are described and discussed in Chapter 4.

3.1 Development of the Foundation Corpus (FOCUS)

The background to and nature of a corpus was explained in Chapter 2 (Section 2.11, p. 77). Here I describe how the Foundation Corpus (FOCUS) was developed.

FOCUS was developed in 2012 and comprises several thousand examples of undergraduate and postgraduate student writing consisting of over three million words drawn from the following university departments: biology, business, chemistry, physics, sport, criminology, sociology, earth sciences, engineering and computer sciences, history, medicine, philosophy, psychology and sport. These student writings may be regarded as "*apprentice performances*" which Tribble (1997) cautions against using as corpus data. However, the function of FOCUS is to help potential undergraduates understand the use of scientific language within the context of the community of practice to which they intend to progress. FOCUS provides students with authentic examples of student writing up to a maximum of 200 characters from these communities of practice. Therefore, in this setting, student writings can be considered "*expert*" rather than apprentice performances. Hence, they illustrate to the potential undergraduates how students within the same institution are using language.

3.1.1 Protocol for text inclusion

Acquiring texts to include in a project of this nature is always difficult as it requires the co-operation of a range of different people (Alsop & Nesi, 2009, p 76 -81). The agreement and cooperation of the relevant departments and the individual students is required. Each department identified students that had scored greater than 60% in summative assignments for programme modules. These assignments included essays, laboratory reports and dissertations. The students were contacted and invited to send in the piece of work with consent to its inclusion in FOCUS (Appendix 18). A response rate in the region of 30% was typically obtained. The text was converted to a .txt file and uploaded unmodified and unedited unless aspects did not convert clearly to the .txt format *e.g*. chemical equations, formulae and mathematical symbols. The files are stored on a university server. The introductory chapters from masters and PhD theses from each of the departments were included.

3.1.2 Concordancer design

The concordancer is the software that is used to run queries and search the texts. The concordance was designed in-house between January and June 2012 with the support of university Enhancing Student Learning Experience funding. Johns (1991) defines a concordancer as

"*able to recover from the text all the contexts for a particular item (morpheme, word or phrase) and to print them out in a way which facilitates rapid scanning and comparison. The most usual format is the keyword-in-context (KWIC) concordance in which the keywords are arranged one below the other down the centre of the page, with a fixed number of characters of context to the left and to the right. A useful refinement, particularly where one is concerned with regularities and patternings in large numbers* *of citations, is the ability to sort alphabetically the contexts to the left or right of the keyword so that similar contexts are grouped together*." (Johns 1991, p. 2)

The Key word in context "KWIC" format was utilised for the concordancer. When a key word is entered into the search box, the concordancer software searches the corpus for all occurrences. Figure 3.1 shows outcomes of a search for "molecule". The key word "molecule" is shown in purple in the second column and up to 200 characters of text before and after the key word is shown either side (this can result in parts of words at the ends of the segment). The three columns to the right of the text show the academic level (ranging from Year 0 to PhD), text type such as dissertation (Diss), essay or laboratory report (Lab rep), and university department such as chemistry (CHEM) or engineering and computer science (ECS).

esults in a protein called plastocyanin. This	**molecule**	allows the PSI reactions to occur which pumps	1	Essay	CHEM
now linked the hole generated in the excited	**molecule**	also has a reasonable chance of traveling the	PhD	Diss	CHEM
increase in the limiting area of the adhering	**molecule.**	Also it was found that the load dependence o	PhD	Diss	CHEM
s a change in vibrational energy level in the	**molecule.**	An important experimental form of vibration	3	Diss	CHEM
d that could possibly be made between a water	**molecule**	and an iodine molecule. So therefore overall	0	Lab rep	CHEM
riginating from the photolysis of the water	**molecule,**	and ATP, reduce the CO2, now a part of GP,	1	Essay	CHEM
e key idea in this research as it is a chiral	**molecule**	and biocompatible with biological substances.	PhD	Diss	CHEM
ily this is mainly due to water being a polar	**molecule**	and covalent bonds are non-polar. These are n	0	Lab rep	CHEM
not break. The diagram below shows an iodine	**molecule**	and how two iodine molecules are attracted to	0	Essay	CHEM
gases. Among them, the ease of tailoring the	**molecule**	and improved sensitivity and selectivity mak	PhD	Diss	ECS

Figure 3.1 Screenshot of a FOCUS search for the key word "molecule"

The screen can be set to show 20, 40 or 100 search returns. If a key word has many results a random 200 results examples are displayed. A word cloud facility enables students to see which words are closely associated with the keyword. For example the word *pressure* is frequently associated with *gas* (see figure 3.2) but also has strong associations with *container, temperature, reaction* and *rate*.

A more advanced search can be performed which limits findings by degree level (from Year 0 to PhD), text type such as essay or laboratory report, or department.
A "wild card" function using the "%" symbol enables users to search for all forms of a word family. For example, searching for *combin%* would return: *combination, combinations, combinatorial, combine, combines, combined,* and *combining*. The wild card symbol allows users to explore particular affixes, such as the search for "%icity" shown in Figure 3.3.

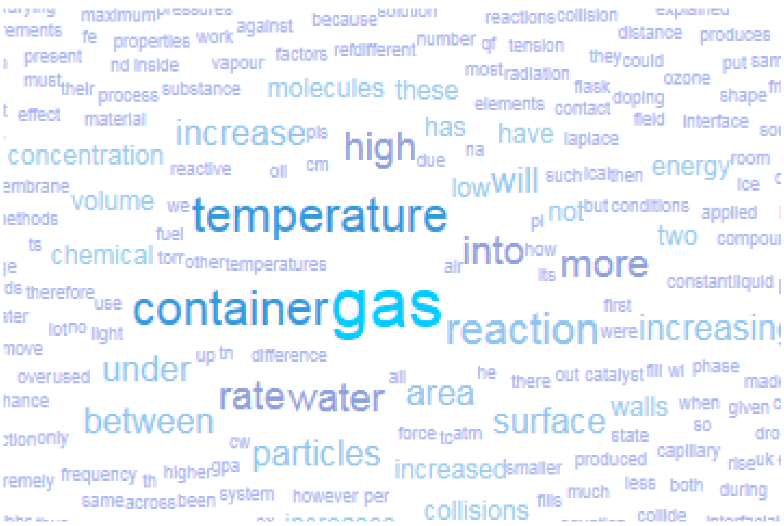


Figure 3.2 FOCUS word cloud associated with the word *pressure*

is defined as a measurement of the acidity or	**basicity**	of a solution (Mesner and Geiger, 2010). In m
ystem. 1.3.3.2 Mechanism and Kinetics The	**simplicity**	of adiabatic calorimetry as a reaction probe
e acidity of carboxylic acids as well as the	**basicity**	of amino groups.5 All the above properties h
side of the laboratory, for example to ensure	**authenticity**	of banknotes, in the postal service and even
d other useful properties.12 Furthermore, the	**stereospecificity**	of diene polymerization has created interest
nate oligonucleotide h) as shown in Scheme 8.	**Electrophilicity**	of h) is increased by imidazole activation, I
constraints. This affects the efficiency and	**specificity**	of interaction and binding with the target mo
ons 1.6.2 and 1.6.4 respectively. 1.5.3	**Toxicity**	of lanthanide complexes In general, all the
ddition, control experiments demonstrated the	**specificity**	of ODF-conjugated antibodies for their target
gated extensively with a view to managing the	**hydrophobicity**	of polymer surfaces is the use of block copol
hich is consequently forced to stall. The	**cytotoxicity**	of some antibiotics originates from their abi
e (+)enantiomer can be used, due to the high	**toxicity**	of the (-)-isomer48. Similar behaviour to 5-F
was due to the ionic liquid increasing the	**nucleophilicity**	of the [18F]fluoride ion even under hydrous c
ed to the ambiphilic nido-cage (Scheme 10).	**Lipophilicity**	of the carborane amino acids can be altered b

Figure 3.3 Results from a wildcard "*%icity"* search

Students use this type of search to deduce meanings of affixes. FOCUS is available to all potential undergraduates via a login page and an instructional video shows how to use the tool. The resource was introduced to students in the teaching activity in week 1 (Table 3.1) where they learnt how to carry out searches and interpret results.

3.2 Organisation of Foundation Chemistry teaching.

In the first term, October to December, the biology, biomedical science, chemistry, computer science, engineering, geology, medicine, pharmacy and physics potential undergraduates complete the core foundation chemistry module worth 20 credits. This module comprises six hours per week of teacher/student contact time divided into one 3h theory session and one 3h practical session. The content includes atomic structure, the Periodic Table, acids and bases and rates of reaction (Appendix 21). A timetable showing the topics taught and the schedule of language focused activities is presented in Table 3.1. Summative assessment consists of a laboratory report (10%), assignment (30%) and examination (60%) (Appendix 21).

Biology, biomedical science, chemistry, medicine and pharmacy potential undergraduates continue with chemistry in the second and third term with a 10 credit Advanced Chemistry module that includes organic chemistry, Born-Haber cycles, electrochemistry, equilibria and acids and bases (Appendix 21). Summative assessment is by examination (100%) (Appendix 22) For both modules, the content is delivered via Powerpoint® presentations supported by course handbooks (Appendix 21). There is a recommended reading list which includes A-level textbooks such as Gent and Ritchie (2010), websites resources such as http://www.chemguide.co.uk and wider reading.

3.3 Language focused activities

The language activities aimed to address Research Question 3 (Chapter 1, Section 1.4.3, p. 25). They were designed to: develop understanding of key vocabulary, the links between words and their origins (Chapter 2, Sections 2.4 – 2.6, p. 44); develop learner confidence in using vocabulary orally and in their written work (Chapter 2, Section 2.7.1, p. 60); promote meta-language discourse (Rincke, 2011; Chapter 2, Section 2.10.2, p. 75); use FOCUS and DDL (Johns, 1991; Chapter 2, Section 2.11, p. 77) to explore chemical language usage.

The nature and organisation of the individual activities are described. The sequence of activities across the academic year was designed to explore the variety of ways that language focused activities can be implemented within a chemistry curriculum. Rees, Bruce and Nolan (2013) provide further discussion of these activities.

Week	Topic	Summary content	Vocabulary relevant to the CLDT or interview scenarios (Chapter 4)	Language activity	Informed by
1 October	Atomic structure Elements and compounds	Development of ideas of atomic structure Explanation of the Bohr model Determining number of protons, electrons and neutrons Chemical reactions to illustrate chemical change, explore understanding of elements and compounds and chemical reactions.	atom, molecule, element, compound, combustion, neutral	Chemical language diagnostic test (CLDT) Personal Glossaries Figure 3.4) **FOCUS**	Pyburn et al. (2013) Wellington and Osborne (2001). ZPD (Vygotsky, 1962) Spolsky (1989)
2	Relative atomic mass (RAM) Amount of substance. Empirical formula	Develop understanding of relative atomic/molecular mass. Calculate RAM from percentage abundance data Calculate amount of substance in moles from mass. Undertake practical experiments to determine the empirical formula of magnesium oxide and copper oxide	atom, molecule, element compound, mole relative atomic mass, reduction	Affixes **FOCUS**	Development of "word attack" skills (Herron, 1996) Sutton (1992) DDL (Johns, 1991)
3	Electron configurations	Electron configurations of the first 20 elements determined using $1s^2$, $2s^2$ etc	atom, molecule, element compound, covalent,	Mini-whiteboards	Social constructivism and ZPD (Vygotsky,

	Bonding and structure	Introduced to ionic and covalent bonding, giant lattices and molecular structures. Practical experiments investigate the physical properties of ionic and covalent compounds.	immiscible, insoluble, electron, H_2O/OH_2		1962) Spolsky (1989)
4	States of matter intermolecular forces Shapes of molecules	Kinetic theory discussed as a basis for changes in state. Occurrence of different intermolecular forces discussed. Shapes of molecules explored e.g tetrahedral, octahedral.	atom, molecule, element, compound, solid, liquid, gas, kinetic energy, intermolecular forces, dipoles, hydrogen bonding	Word association. **FOCUS**	Social constructivism (Vygotsky, 1962) DDL (Johns, 1991) Word games (Herron, 1996)
5	The Periodic Table	Historical development of the Periodic Table and trends in main groups discussed. Practical experiments explore trends in group 1 and group 7	atom, molecule, element compound, inert	Word origins	Telling the scientific story (Sutton 1992)
6	Acids and bases Volumetric analysis	Students introduced to the pH scale and Brønsted Lowry acid base theory. Reactions of acids and bases explored.	acid, base, neutralisation, weak, strong, solution, salt, dissociates	Word explanations	social constructivism (Vygotsky, 1962)

7	Mid term review Concentration calculations Equilibrium	Content covered reviewed with a formative test. titration experiments undertaken and amount of substance from concentration covered. Principles of physical and chemical dynamic equilibria illustrated with practical experiments (Iodine and cobalt chloride).	acid, base, neutralisation, weak, strong,	Extending meaning of *pressure.* **FOCUS**	social constructivism, ZPD (Vygotsky, 1962) Learning progressions (Corcoran, Mosher and Rogat (2009)
8	Oxidation states Rate of reaction	Determining oxidation states of elements in different compounds Factors affecting rate of reaction. Practical assessment laboratory report – effect of temperature / concentration on the reaction of marble chips and acid.	atoms, elements, molecules, compound, acid, base, neutralisaton	Picturing words	Social constructivism (Vygotsky, 1962) Word games (Herron, 1996)
9	Enthalpy changes	exothermic and endothermic reactions investigated and enthalpy changes calculated. Hess's Law used to calculate enthalpy changes	Combustion, exothermic, bonds	CLDT	Pyburn et al. (2013)
10 December	Crude oil Revision	introduction of crude oil and fractional distillation	Combustion, insoluble, synthesis, molecules, intermolecular forces	**FOCUS** and DDL to improve student writing.	Johns (1991)

Table 3.1 Summary of the teaching sequence for the Core Foundation Chemistry module from October to December with the language focused activities and their theoretical basis indicated

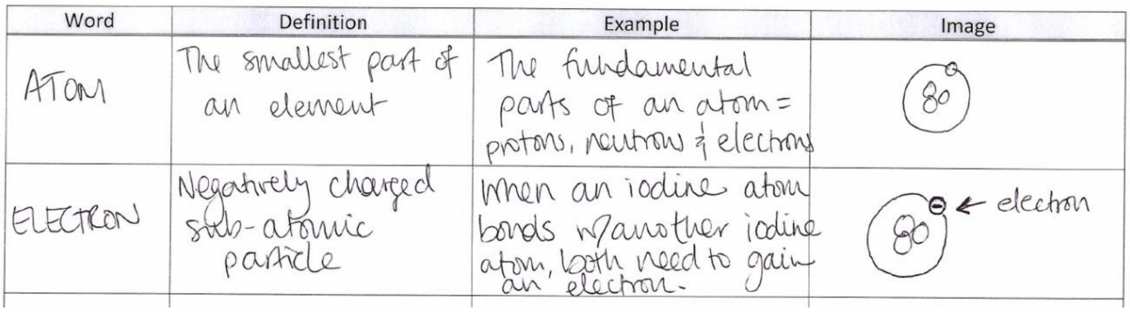
Week	Topic	Summary content	Vocabulary relevant to the CLDT or interview scenarios	Language activity	Informed by
11 January	Organic chemistry naming compounds	Separation of crude oil revisited and naming of organic compounds explained.	atom, molecule, element, compound	word origins - benzene	The scientific story – Sutton (1992)
12	Organic chemistry	Practical – aspirin hydrolysis	Solution, synthesis, terminated, initiated	none	
13	Alkanes, alkenes and aromatics	Structure and halogenation of alkanes, alkenes and aromatics including mechanisms	atom, molecule, element, compound, polarity, dipole, electrophile, Br_2/2Br	multiple contexts – saturated **FOCUS**	DDL (Johns, 1991) Interlanguage (Selinker , 1972)
14	The Victorian Pharmacy	Practical - Reactions of alcohols and carbonyls Identifying unknown (Victorian) chemicals	atom, molecule, element, compound, reduction, solution	Key word glossary	Wellington and Osborne (2001) ZPD (Vygotsky, 1962)
15	carboxylic acids, esters, fats and polymers	structure and reactions to esters, triglycerides and polymers (addition/condensation) impact of diet and heart disease	Intermolecular forces, insoluble, saturated	Key word glossary	Wellington and Osborne (2001) ZPD (Vygotsky, 1962)

16	electrochemistry	Practical – electrolysis of brine constructing electrochemical cells and calculating cell potentials and cell equations	atom, molecule, element, compound, cell	Directed Activity Related to Text (DART)	Wellington and Osborne (2001) Taber (2002)
17	Born-Haber cycles	Born-Haber cycles to calculate lattice enthalpy trends in lattice enthalpy	NaCl (aq)/(l), salt, atom, ion, element, compound, complex	Word explanations	Social constructivism (Vygotsky, 1962) Word games (Herron, 1996)
18	Thermodynamics	Introduction to entropy and Gibbs free energy equation Revision	Exothermic, spontaneous	Mini-whiteboards	Social constructivism ZPD (Vygotsky, 1992)
		EASTER VACATION – 5 weeks			
19	Acids and bases	Calculating pH from hydrogen ion concentration Determining K_a and pK_a Calculating pH of a weak acid	atom, molecule, element, compound, acid, base, solution, weak, salt	multiple contexts – strong and weak **FOCUS**	DDL (Johns, 1991) Interlanguage (Selinker, 1972)
20 May	Equilibria	Dynamic equilibrium and Le Châtelier's principle Calculating K_c	Exothermic, molecule, decomposes	CLDT	Pyburn et al. (2013)

Table 3.2 Summary of the teaching sequence for the Advanced Chemistry module from January to May with the language focused activities and their theoretical basis indicated

3.3.1 Weeks 1, 8, 14 and 15 – Personal glossaries

This activity operates within the students' zones of proximal development (Chapter 2, Section 2.7.1, p. 60) and scaffolds student learning by developing current understanding of new words. It is based on approaches described by Wellington and Osborne (2001 and provides students with one potential strategy to improve their language understanding as they progress through the course. A classroom discussion is initiated about learning meanings of new and unfamiliar words. The advantages and disadvantages of a range of approaches are discussed such as internet search engines, general and specialist dictionaries (online and hard copy) and glossaries in textbooks. Students are introduced to the idea of creating personal glossaries as they encounter new words. Students suggest an example word from the lesson such as *proton* to put into the glossary. Definitions are suggested by the class and compared to a definition obtained from an online dictionary, a FOCUS search provides an example sentence in context and a memorable image is included (Figure 3.4). The activity was revisited in weeks 8, 14 and 16 to encourage students continued usage of the strategy.



Word	Definition	Example	Image
ATOM	The smallest part of an element	The fundamental parts of an atom = protons, neutrons & electrons	
ELECTRON	Negatively charged sub-atomic particle	When an iodine atom bonds w/another iodine atom, both need to gain an electron.	← electron

Figure 3.4 Example of student generated personal glossary

3.3.2 Week 2 - Affixes

This activity develops understanding of scientific affixes. It is informed by ideas of exploring the scientific story as described by Sutton (1992, Chapter 2, Section 2.6, p. 56) and developing "word attack" skills (Herron, 1996, Chapter 2, Section 2.6, p. 58). The activity is guided by the principles of data driven learning Johns, 1991, Chapter 2, Section 2.11.1, p. 77). It is informed by social constructivism (Chapter 2, Section 2.7.1, p. 60) and scaffolds student learning by building on current understanding of scientific words. The activity relates to the affixes section of the chemical language diagnostic test (Chapter 4, Section 4.8.3, p. 111). Initially, students suggest affixes or, if these are not forthcoming, some chemistry words are examined for their affixes. For example, *hydrophilic* contains the prefix *hydro* and the suffix *philic*. Students search for affixes on FOCUS and, based on the sentences obtained, suggest a meaning for the affix (Figure 3.5).

that gives a single strong NMR signal, and a	hydrophilic	part which ensures the water solubility of th
hobic group, which repels the solvent, and a	lyophilic	group which has a strong attraction to the so
henolic proton. This theory lost favour: a	hydrophilic	pathway extending through the protein away fr
oups which are readily deprotonated to form a	nucleophilic	carboranyl anion. Unfortunately, the anion
r is used, it must first be reduced to form a	nucleophilic	Pd(0) species. It is not fully understood how
d its derivative compounds. Rapamycin 49 is a	lipophilic	macrocyclic antibiotic macrolide produced b

Figure 3.5 FOCUS search for -*philic*

3.3.3 Weeks 3 and 18 – Mini-whiteboards

The students are introduced to the mini-whiteboards in week 3 as a tool for writing down suggestions and contributing to discussions. The boards are used specifically to improve understanding of subject specific language. Each student is provided with an A4 (210 x 297mm) size whiteboard, non-permanent marker pen and cloth. The activity is informed by social constructivism (Chapter 2, Section 2.7.1, p. 60) and operates within the students' zones of proximal development (Chapter 2, Figure 2.7 p. 62). Students are asked to write a chemistry word they have recently come across on one side of the boards. The boards are then passed on to another student who is then asked to write an explanation of that word on the other side (Figure 3.6). The teacher collects in the boards and then discusses the written explanations to see if students can correctly identify the word. In this way, the teacher scaffolds the learning and develops student chemical language understanding. FOCUS can be used if there are examples requiring further explanation and this activity developed understanding of words in all sections of the CLDT.

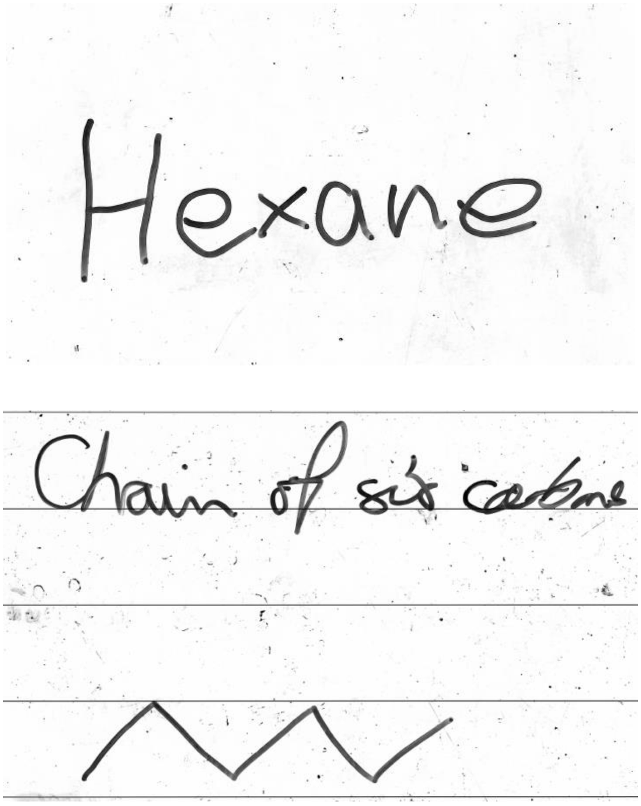


Figure 3.6 Mini-whiteboard key word and student explanation for *hexane*

3.3.4 Week 4 – Chemistry word association

This activity is informed by social constructivism (Vygotsky1962; Chapter 2, Section 2.7.1, p. 60) and the role of word games in chemistry teaching (Herron, 1996). It promotes contributions from all students and encourages the students to enter into subject specific discourse. It begins with one student choosing a non-chemistry word such as *cat*. The next student states a word associated with *cat* such as *dog* and this continues around the class until someone suggests an incorrect word, repeats a word or hesitates for more than a few seconds. The game is repeated using a chemistry word and students are restricted to associated scientific/chemistry words. Less confident students can work in teams to find associated words. The FOCUS word cloud facility can be used to provide examples of related words. This activity relates to the lexical sections (kinetic theory, acids and bases) in the CLDT.

3.3.5 Weeks 5 and 11 – Word origins (Natrium, Benzene)

These activities are based on telling the scientific story (Chapter 2, Section 2.6, p.56). Discussions about the Periodic Table provide opportunities to share the stories behind element symbols. This is useful when no obvious association between name and symbol is apparent, for example, sodium (Na) and potassium (K). The sodium story includes the ancient Egyptians preserving mummies with *Natron* (sodium carbonate), which became *natrium* in Latin leading to the symbol of sodium becoming *Na*. Stories like this provide context and reason for the symbols so that they are less likely to be seen as labels but have an interpretative meaning (Sutton, 1992).

In week 11, the story of the *benzene* (Chapter 2, Section 2.6, p. 58) is described. The story is further enhanced by providing benzoin essential oil for students to see and smell. This helps strengthen associations with words such as *organic* and *aromatic*. This strategy is particularly relevant to the CLDT Affixes section.

3.3.6 Weeks 6 and 17 – Word explanations

In this activity, students write a key word on a mini-whiteboard followed by five further associated words underneath. A student describes the key word for other students to guess without saying the words underneath. For example, if the key word is *acid* then the student may not be allowed to say *alkali, vinegar, neutralise, indicator or red*. This activity is informed by social constructivism (Vygotsky 1962; Chapter 2, Section 2.7.1, p. 60) and the role of word games in chemistry teaching (Herron, 1996). It helps students think about meanings of words and connections between them. It relates to the lexical sections (kinetic theory, acids and bases) in the CLDT.

3.3.7 Week 7 – Using FOCUS to extend meaning of "Pressure"

This activity develops understanding of the term *pressure* by increasing students' awareness of words associated with *pressure* and multiple contexts. The task uses the FOCUS word cloud facility. The activity aims to work within students' zones of proximal development (Chapter 2, Section 2.7.1, p. 60) by establishing and then extending current understanding of word meaning. The activity lasts around 40 minutes and takes place in a computer room. Three students work together to construct a group mind map summarising words associated with the key word, showing links to explain connections. Individual students enter the key word into FOCUS. The word cloud is examined (Figure 3.2) for new words not included in their original mind map. Example sentences to understand context are investigated. New words are added to the maps with links explaining connections. Students would undertake internet searches to find out the meaning of new unfamiliar words. The expanded mind map is discussed with the whole group.

Extensions and variations include: students constructing a whole-class mind map, with each group contributing examples from their mind maps; or topic specific usage may be explored by comparing searches in different subject areas such as chemistry or earth sciences.

3.3.8 Week 8 – Picturing words

Each student writes down a relevant word on a mini-whiteboards. These are collected together and a student chooses one of the words and draws a picture to represent the word. The other students try to guess the answer. This activity is informed by social constructivism (Vygotsky 1962; Chapter 2, Section 2.7.1, p. 60) and the value of word games in chemistry teaching (Herron, 1996). It helps familiarise students with vocabulary and promotes the use of imagery to convey meaning. Figure 3.7 is an example for the key word *electrophile.*

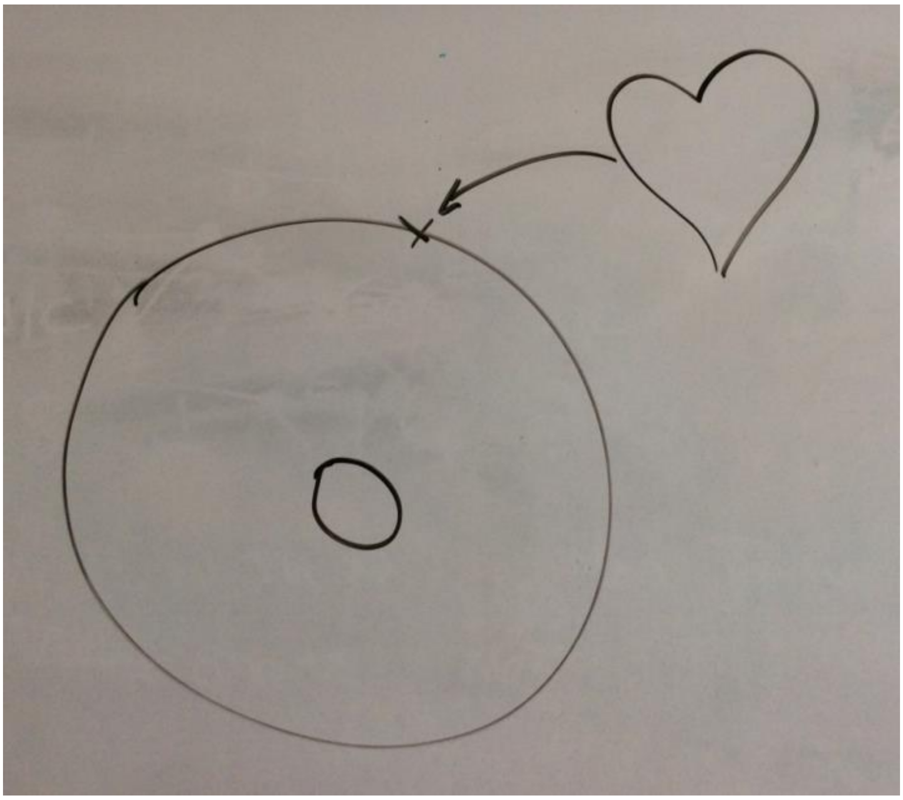


Figure 3.7 A “picturing words” example representing *electrophile*

3.3.9 Week 10 – Using FOCUS and DDL to improve student writing

Examples of student writing that could be improved are collated from submitted work. Using the principles of DDL (Johns, 1991, Chapter 2, Section 2.11.1, p. 77), FOCUS provides alternative suggestions. For example, the word *proves* in the sentence "*this proves that the reaction was exothermic*"**.** A FOCUS search for *prove*s returns thirteen examples in chemistry texts. Students provide alternatives, for example, *shows, demonstrates, suggests.* A FOCUS search for synonyms of *proves* demonstrates that these alternatives were much more frequent. There are 452 occurrences of *demonstrates* for example.

Individual sentences are extracted, for example, *"Some recent research suggests that the ozone hole may have a direct effect on climate change in the southern hemisphere"*. The impact on meaning is discussed by replacing *suggests* with *proves* in the sentence.

A second example is "*omitted"* in the phrase "gas was *omitted*". The phrase is unclear as the student meant *emitted*. A FOCUS search for *emitted* revealed this word is not associated with gas production but with photons, light and radiation (Figure 3.8).

states. Because the energy of the photon	**emitted**	equals the energy gap, it is an example of co
electrons is in the form of photons. Light is	**emitted**	from all diodes but only those with large e
ase diagnostics and treatment. Radiation is	**emitted**	from a source inside the body with many appli
ncrease in activity. IR radiation is actively	**emitted**	from all objects and no external light source

Figure 3.8 Results of a search for *emitted* in FOCUS (chemistry)

Alternative suggestions sought included *produced* and *released*. *Produced* occurs 730 times in FOCUS chemistry texts, showing several examples relating to gases. *Released* revealed 155 occurences, some referring to gases. Therefore, these words may be a suitable alternative for *emitted*. However, closer examination reveals subtle difference between the use of the two words. For example, *released* refers to gases being released into the atmosphere, for example, "*Although the use of biofuels have significantly reduced the amount of greenhouse gases* ***released*** *into the atmosphere*"

Produced relates to where a gas is made, for example, "*However, in 1937, Robert Hill discovered that oxygen is still* ***produced*** *by chloroplasts in the absence of* CO_2*"*

Hence, DDL has addressed two language issues; the correct usage of *emitted* rather than *omitted* and differences between a gas being *produced* and *released.* The content of this activity is determined by examples from students' work. This provides relevance and authenticity to address linguistic and academic writing difficulties. The activity models use of FOCUS to check word usage or to improve phrasing. The activity relates to the word choice section of the CLDT (Chapter 4, Section 4.8.3, p. 112).

3.3.10 Week 13 and 19 – Multiple contexts

This activity uses DDL to explore word meaning in multiple contexts. It is informed by interlanguage (Chapter 2, Section 2.10.2, p. 75) to develop student understanding. The word *saturated* is introduced in the context of carbon - carbon double bonds in hydrocarbons. In different contexts, however, the word *saturated* has alternative meanings. Figure 3.9 shows six lines from a search for *saturated* in the FOCUS chemistry texts and reveals three different contexts: *saturated lipids* (line 1), *saturated by light* (line 5) and *saturated solution* (line 6).

1	transition temperatures change with different	saturated	and unsaturated lipids. Ternary mixtures c
2	rs note the distinct electronic properties of	saturated	and unsaturated NHCs, particularly with respe
3	c compound. Fluorine reacts readily with most	saturated	and unsaturated organic compounds and can do
4	ates requires that the air water interface be	saturated	before they form (chapter 3). However, it app
5	lkovsky, 2010), and its absorption can become	saturated	by light in the infrared region due to the la
6	ld collect the vapour and bubble this through	saturated	calcium hydroxide solution (lime water). If c

Figure 3.9 FOCUS search for *saturated*

In week 19, the meaning of *strong* and *weak* is explored. FOCUS is used to provide examples of the use of *weak* and *strong* (Figure 3.10) and meanings discussed. Figure 3.7 shows one section of the returns of a search for *strong*. Within these seven examples, *strong* is used in four different contexts: *strong absorption* (line 1), *strong acid* (lines 2 and 3), *strong affinity* (line 4) and *strong bonds* (lines 5, 6 and 7). This search clarifies use of *strong* and introduces other words such as *affinity* and *absorption*.

1	0 to 750 nm though this is compensated by the	strong	absorption of PC71BM over the visible range o
2	n seconds. The reaction that occurs between a	strong	acid and a strong base is so fast that the re
3	itic oxide, made by exposing graphite to very	strong	acids and therefore causing oxidation to occu
4	of a biotin-labelled protein makes use of the	strong	affinity of biotin towards the protein strept
5	hbouring ion or ions. This attraction is very	strong	and a large amount of energy is required to b
6	fluorine bonds within the molecule are very	strong	and are not susceptible to van der Wahls for
7	able outer shells. This covalent bond is very	strong	and difficult to break. Figure 5 is an image

Figure 3.10 FOCUS search for *strong*

3.3.11 Week 16 – Directed Activity Related to Text (DART)

This Directed Activity Related to Text (DART) (Wellington and Osborne, 2001) requires students to read an article about a hydrogen fuel cell and answer a series of structured questions (Appendix 20). The activity is designed to develop active reading strategies (Wellington and Osborne, 2001). The first question "*What does the phrase 'fuel cells generate energy through electrochemical oxidation' mean?"* aims to explore student understanding of *electrochemical oxidation* using knowledge gained during the lesson. The answer cannot be determined from the text. A good answer states that hydrogen used in the fuel cell loses electrons during the reaction. The second question "*Why is a fuel cell thought to be more efficient for producing electricity than burning the fuel?"* can be answered directly from the text. A good answer states that the electrochemical cell converts chemical energy directly into electrical energy without first becoming thermal energy. The third question "*Summarise the chemical processes that ultimately result in the production of electricity at this plant i.e. start with the electrolysis of brine.*" reinforces learning about the electrolysis of brine and then extends the explanation to a hydrogen fuel cell. A good answer will explain how hydrogen is generated during the electrolysis of brine and how this combines with oxygen in the fuel cell to generate a voltage. The final question "*Do you think this is an efficient process for the production of electricity from hydrogen?"* requires the students to reflect on the overall process and provide an opinion. A good answer will recognise the high energy input required for the electrolysis of brine compared to the energy generated by the hydrogen. Alternative uses of the hydrogen may be suggested. Responses are discussed with the class as well as reading strategies.

3.4 Summary

This chapter described the design and development of the FOCUS project and the range of language focused activities incorporated in to the teaching schedule. The functionality of FOCUS and how this was used in teaching was explained. These corpus linguistics activities involved developing understanding of scientific affixes (Section 3.3.2), lexical knowledge of topic words (Section 3.3.7), understanding of language in laboratory reports (Section 3.3.9), and understanding of words in multiple contexts (Section 3.3.10), The other language focused activities aimed to develop student learning strategies with personal glossaries (Section 3.3.1), encourage student contributions and develop confidence with mini-whiteboards and word games (Sections 3.3.4, 3.3.6, 3.3.8), explore the origins of words (Section 3.3.5) and develop student reading strategies with DART (Section 3.3.11). The next chapter describes the methodology used to investigate students' chemical language understandings and usage.

Chapter 4

Methodology

4.1 Introduction

This chapter describes the methodology adopted to answer the research questions. Figure 4.1 summarises how the research tools adopted informed the research questions. Section 4.2 summarises the project timeline. Sections 4.4 to 4.7 discuss sampling, bias, validity and reliability and ethical considerations. Section 4.8 explains the development of the chemical language diagnostic test (CLDT) including the pilot version. Statistical analysis of the CLDT data is explained in Section 4.9. The use of eye tracker software to test reading comprehension is detailed in Section 4.10 including a description of data analysis. Section 4.11 describes the selection of the interview students and interview analysis.

4.2 Timeline

The study commenced in academic year 2011/12 with recruitment of the first interview students. Further interview students were recruited in 2012/13 and 2013/14. The CLDT pilot was undertaken in 2012/13 and the CLDT was delivered in 2013/14 and 2014/15. Table 4.1 summarises the research timeline including the development of the teaching activities strategies (Chapter 3, Section 3.3 p. 85).

4.3 Methods

This is a unique and longitudinal case study (Yin, 2003) of innovative teaching practice in a specific teaching and learning context. Stake (1995) describes a case as a "*functioning specific*" and "*an integrated system*". Bryman (2008) states that a case study is where "*the case is an object of interest in its own right and the researcher aims to provide an in-depth elucidation of it*" (p. 54). A case study may be criticised because the findings derived from it cannot be generalised. 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 groups 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. Engagement with other lecturers in other centres was considered but this was not feasible as substantial training would have been required for the lecturers to successfully apply the language focused activities and subsequent application would likely to have been variable.

The study adopts mixed methods using qualitative and quantitative principles as described by Creswell (2013) and Denzin and Lincoln (2000). A mixed methods design was undertaken to enable triangulation between the different data collection methods used. The CLDT provided data on student understandings of aspects of chemical language whilst student interviews investigated the students' ability to use language in personal explanations. The eye tracker study provided data indicating how students access and read text. Figure 4.1 summarises how the different methods used answered the research questions.

Year	Month	Activity	Research Question
2011	October	Interview students recruited. Language based teaching strategies trialled. Literature review commenced.	1,2,3,4 3,4 1,2,3,4
	November	Student interviews.	1,2,3,4
2012	April	Student interview.	1,2,3,4
	June	CLDT pilot devised. Teaching activities devised. Initial literature review completed. FOCUS developed.	1,2,3 3,4 1,2,3,4 3,4
	October	CLDT pilot administered. Interview student recruited. Teaching activities implemented.	1,2,3 1,2,3,4 3,4
	November	Student interview.	1,2,3,4
2013	May	CLDT pilot repeated Student interviews.	1,2,3 1,2,3,4
	June	Student interview.	1,2,3,4
	July	CLDT revised.	1,2,3
	October	CLDT hard copy administered. Interview students recruited. Teaching activities implemented.	1,2,3 1,2,3,4 3,4
	November	Student interviews.	1,2,3,4
	December	CLDT hard copy administered.	1,2,3
2014	January - March	Student interviews.	1,2,3,4
	May	CLDT online administered. Student interviews.	1,2,3 1,2,3,4
	August	Student interview.	1,2,3,4
	October	CLDT online administered. Teaching activities implemented.	1,2,3 3,4
	November	Eye tracker task administered.	1
	December	CLDT online repeated Student interviews.	1,2,3 1,2,3,4
2015	April	Eye tracker task repeated	1
	May	CLDT online repeated	1,2,3
	June	Student interviews.	1,2,3,4
	July - December	Data analysis and thesis writing	1,2,3,4
2016	January - September	Thesis writing	1,2,3,4

Table 4.1 Project timeline

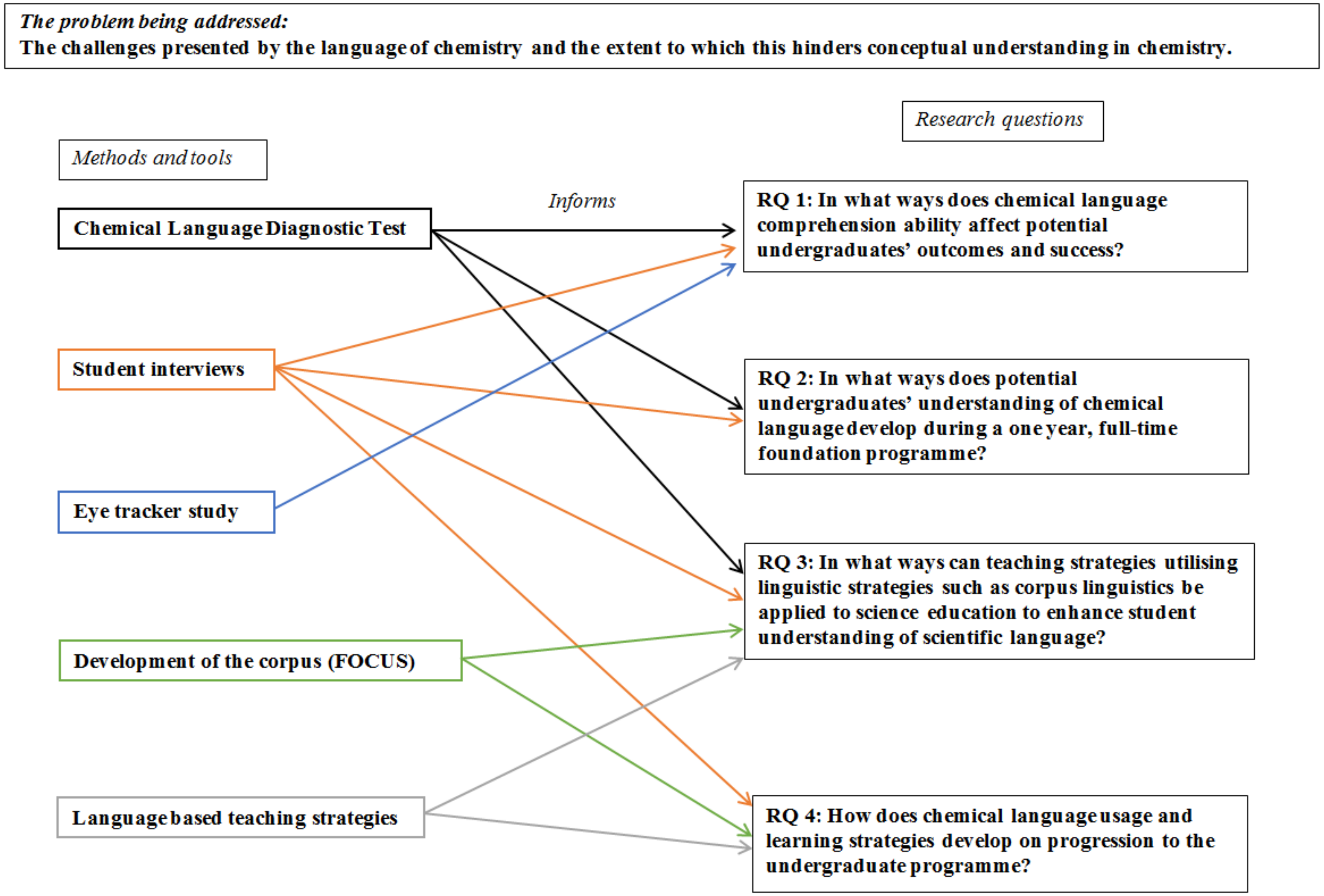


Figure 4.1 Summary of methods and tools used to inform the research questions

4.4 Sampling

The sample comprised the entire population of students studying Year 0 chemistry courses at one institution. This represents a specific population of interest in a unique teaching and learning context (Bryman, 2008). Chemical Language Diagnostic Test (CLDT) was obtained from the entire student cohort and the interview students were a sub-set of the population. The interviews students had a range of different backgrounds and were a representative sample of the population. Details of the sample are provided in Chapter 5 (Section 5.2, p. 136).

4.5 Bias

The study design offers potential for author bias. The author was teaching the students so was in a position of authority whilst undertaking the research. All students were informed about the project and full ethical protocols were followed (Section 4.11).

4.6 Validity and reliability

Reliability is concerned with the reproducibility of results. Carmines and Zeller (1979, p. 11) suggest that reliability is the "tendency toward consistency found in repeated measurements in the same phenomenon". Therefore, reliability is demonstrated when consistent results are obtained in different situations.

Validity according to Westmayer (1981) is the extent to which the method measures what it is said to measure. In educational research, external and internal validity are differentiated. External validity is the extent to which results can be generalised to the wider population (Cohen, Manion and Morrison, 2000, p 109). Internal validity seeks to demonstrate that the data can explain a particular event (Cohen, Manion and Morrison, 2000, p. 107).

In this thesis, validity is examined by triangulation of CLDT, eye tracker and case study data. Internal validity of the CLDT instrument and case studies are considered in terms of the extent to which they measure chemical language understanding. External validity could be demonstrated through using the CLDT and scientific scenarios in different settings. Reliability of the CLDT and case study data is examined by repeated use over time and correlation between the two methods.

4.7 Ethical considerations

This study was undertaken under BERA (2011) ethical guidelines. These correlate with the Foundation Centre's Departmental Ethics Committee. Copies of relevant agreements are provided in Appendices 18 and 19. The project objectives were discussed with all potential participants. Students were informed about the levels of input required (Appendix 18). Data were gathered in confidence and were not used for any purpose other than preparation of this thesis and associated publications. Students could withdraw from the study at any time. Students' names were removed and substituted with pseudonyms. Data is not stored in a format that permits link to real names.

4.8 Chemical language diagnostic test (CLDT) development

The chemical language diagnostic investigates students' understandings of chemical language. Within the project, the test was developed through several iterations into an online format that could be completed by students within 30mins, providing instant feedback.

4.8.1 CLDT pilot, academic year 2012/13

The CLDT pilot assessed understanding of thirty chemical words using a multiple choice format. The selected words are relevant to the foundation chemistry course. The words were selected using suggested classifications by Wellington and Osborne (2001; Chapter 2, Table 2.3, p. 45) and results obtained by Cassels and Johnstone (1985; Chapter 2, Section 2.4, p. 46). Twenty are "non-technical" and ten words are "scientific". Non- technical words are words widely used in but not restricted to science The non-technical words were identified as problematic by Cassels and Johnstone (1985). Scientific words are specifically developed for science. Table 4.2 lists the words, showing when and how frequently each occurs during the course. Low frequency indicates that the word may be used occasionally during teaching (less than once per week). Medium frequency indicates the word would be used at least once in every lesson during the weeks shown. High frequency indicates the word was repeatedly used every lesson during the relevant weeks.

Word	Occurrence during Year 0	Frequency[1]
Non-technical		
disintegrate	throughout	low
negligible	throughout	low
impact	throughout	low
contract	throughout	low
spontaneous	throughout	low
source	throughout	low
complex	throughout	low
tabulated	throughout	low
accumulate	throughout	low
consecutive	throughout	low
converse	throughout	low
constituent	throughout	low
exert	throughout	low
displaces	week 5	low
crude	weeks 10 – 15	medium
salt	week 3 onwards	medium
reduction	week 2 onwards	medium
organic	week 10 onwards	medium
shell	week 1 onwards	medium
equilibrium	weeks 7,19, 20	high
Scientific		
nucleophile	weeks 10 - 15	low
solvent	week 3 onwards	low
distillation	weeks 10 - 15	medium
ionic	week 3 onwards	medium
lone pair	week 4 onwards	medium
endothermic	week 1 onwards	medium
polymer	week 15	medium
subatomic	weeks 1 - 3	medium
electronegative	week 4 then weeks 11 - 15	high
electrolysis	weeks 5 and 16	high

[1]See text for an explanation of frequency

Table 4.2 Words selected for the CLDT pilot, showing frequency of occurrence in the foundation chemistry course

The CLDT pilot used a multiple choice format with the key word presented in a scientific context. The correct definition and three alternatives were provided. The non-technical words used original questions from Cassels and Johnstone (1985) and original questions were produced for the scientific words by the researcher. The CLDT pilot was administered at the start (October 2012) and at the end (May 2013) of Year 0. The test was presented online in a Google document format (Rees, 2012) and the students had 40 minutes to complete the test in a computer room during a chemistry theory lesson. Thirty three students completed the test in October 2012 and twenty four in May 2013.

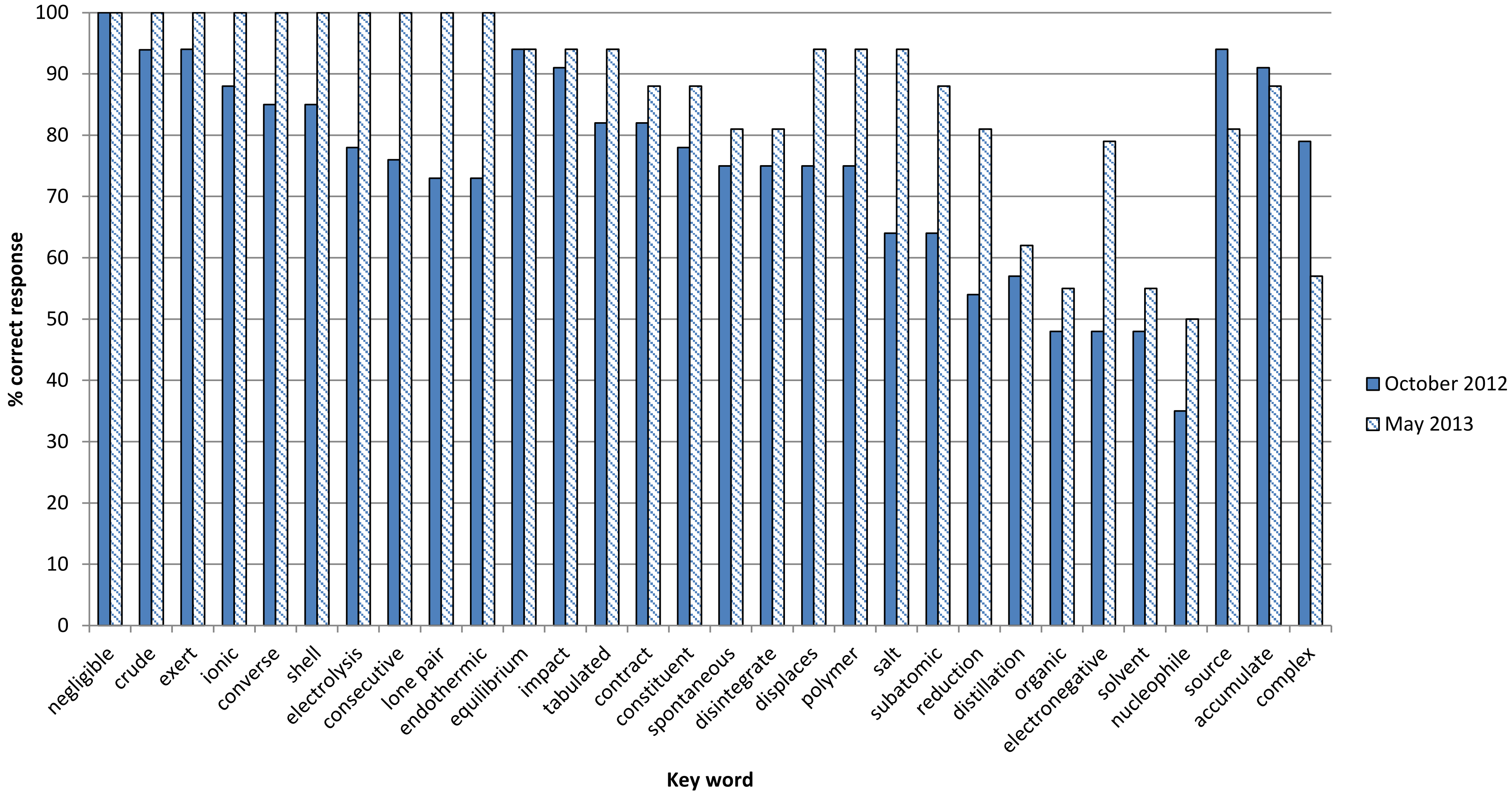
4.8.2 CLDT pilot results

Table 4.3 and Figure 4.2 show results of the CLDT pilot. There was variation in correct response rates. This variation was observed in both scientific and non-technical words. In October, between 30 and 60% of students gave a correct response to six words indicating that understanding of these words was problematic for many students. Two words were non-technical: *reduction* and *organic.* Four words were scientific: *distillation, electronegative*, *solvent* and *nucleophile*. Although there was an improvement in May 2013, these words had a correct response rate of between 50% and 81% in May indicating some students continued to misunderstand meaning. These words are shaded red in Table 4.3. Eleven words were misunderstood by some students in October with correct responses between 64% and 94%. Some students continued to misunderstand these words in May with correct responses between 81% and 94%. Nine of these words were non-technical: *equilibrium, impact*, *tabulated*, *contract*, *constituent, spontaneous, disintegrate, displaces* and *salt*. Two words were scientific: *polymer* and *subatomic*. These words are shaded amber in Table 4.3. Ten words had correct responses of between 73% and 100% in October and had no incorrect responses in May. Six of these words were non-technical: negligible, crude, exert, converse, shell and consecutive. Four words were scientific: ionic, electrolysis, lone pair and endothermic. These words are shaded green in Table 4.3. Three words had a lower correct response rate in May 2013 than in October 2012. These words were all non-technical: *source, accumulate* and *complex*. These words are shaded grey in Table 4.3.

Word	Word type	% correct response	
		October	May
negligible	non-technical	100	100
crude	non-technical	94	100
exert	non-technical	94	100
ionic	scientific	88	100
shell	non-technical	88	100
converse	non-technical	85	100
electrolysis	scientific	78	100
consecutive	non-technical	76	100
lone pair	scientific	73	100
endothermic	scientific	73	100
equilibrium	non-technical	94	94
impact	non-technical	91	94
tabulated	non-technical	82	94
contract	non-technical	82	88
constituent	non-technical	78	88
spontaneous	non-technical	75	81
disintegrate	non-technical	75	81
displaces	non-technical	75	84
polymer	scientific	75	84
subatomic	scientific	64	88
salt	non-technical	64	84
distillation	scientific	57	62
reduction	non-technical	54	81
organic	non-technical	48	55
electronegative	scientific	48	79
solvent	scientific	48	55
nucleophile	scientific	35	50
source	non-technical	94	81
accumulate	non-technical	91	88
complex	non-technical	79	57

Note: see text for explanation of colour coding.

Table 4.3 Results of the CLDT pilot



October, n = 33; May, n = 24

Figure 4.2 Percentage correct responses in October 2012 and May 2013

Table 4.4 shows the alternative choices in May 2013 for the “red” words *reduction*, *distillation*, *organic*, *electronegative*, *solvent* and *nucleophile*.

Key word	Alternative meaning	% response
reduction	the rate at which a chemical species loses electrons	19
distillation	Repeated heating and condensing	25
	The breaking of long chain molecules into shorter chains	13
organic	A chemical compound of natural origin	45
electronegative	The ability of an atom to gain an electron to form an ion.	25
solvent	A substance that dissolves	38
	A substance that evaporates easily	7
nucleophile	A reacting species that reacts with an acid.	6
	A reacting species that is highly charged.	25
	A reacting species that is an electron donor.	19

Table 4.4 CLDT pilot alternative responses for “red” words

Reduction was confused with oxidation by 19% of students and *distillation* was confused with *reflux* by 25% of students. 45% of students retained the “everyday” meaning of organic rather than the chemistry context of a “carbon based compound”.

Results of CLDT pilot were used to inform the non-technical word section of the 2nd iteration of the CLDT (Section 4.8.3). Words that had been correctly understood in May 2013 (Green words) were excluded from the 2nd iteration of the CLDT. Five non-technical words from the CLDT pilot were included in the non-technical section of the 2nd iteration of the CLDT. Three were classified amber in the CLDT pilot: contract, spontaneous and salt. One word was classified red: reduction. The amber and red words were chosen as they continued to be misunderstood by some students in May 2013. One word was classified grey was also included: complex. This word was included to see if the decrease in understanding observed in the CLDT pilot would be repeated in subsequent years.

4.8.3 The CLDT (academic years 2013/14 and 2014/15 – AY2 and AY3)

The CLDT pilot tested understanding of two categories of words: scientific and non-technical. The 2nd iteration of the CLDT contained six sections to test a broader range of chemical language (Appendix 16). These sections are detailed below.

Section 1 - Affixes

This section tested students' understandings of twenty affixes (Table 4.5) used in chemistry. This section was informed by the value of words as interpretative tools (Sutton, 1992) and knowledge of word roots to "decode" new unfamiliar words (Herron, 1996). The twenty affixes were in a table to be completed with the correct answer selected from a list below the table. One mark was awarded for each correct answer with a maximum score of twenty.

Affix	Meaning	Comments
Hydro-	Water	Frequently encountered during Year 0.
-phobic	Hating	
Iso-	Same	
-phile	Loving	
Omni-	All	*Omni*, *poly* and may be confused.
Poly-	Many	
Micro-	Small	*Micro* and *milli* may be confused.
Milli-	One thousandth	
Intra-	Within	*Intra* and *inter* may be confused.
Inter-	Between	
Exo-	Outside	*Exo* and *endo* may be confused.
Endo-	Within	
Halo-	Salt	Common knowledge of *a halo* does not link to *salt.*
-gen	Maker	Regularly encountered in element names.
-azo	Containing nitrogen	Less commonly known.
-lysis	Break down	Used in a number of words e.g. *electrolysis, hydrolysis*.
Mono-	Single	Common in everyday language e.g. *monorail, monopoly*.
Bi-/di-	Double	Common in everyday language e.g. *bicycle, biped, bifocals*
Ferr-	Containing iron	May be confused with "*fer*" as in *ferment / ferocious*
Macro-	Large	Widely used in science e.g. *macroscopic, macrophage.*

Table 4.5 CLDT pilot alternative responses for "red" words

Section 2 - Fundamentals

This section tested students' understandings of fundamental words *atom, molecule, element, compound* and *ion*. These words are used frequently and students' misunderstandings of meaning have been reported (Karatas, Ünal, Durland, & Bodner, 2013). The use of these words presents challenges for students moving between macroscopic and sub-microscopic levels. The question design used a sub-microscopic diagrammatic representation of atoms and molecules (Figure 4.3). The students were required to select the correct choice from a list of six options. One mark was awarded for each correct answer.

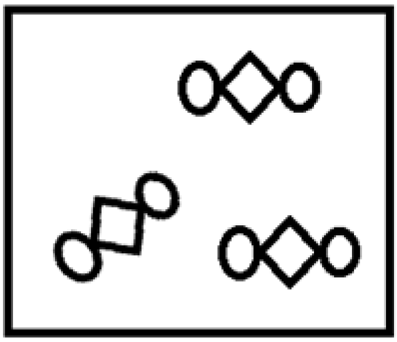
	Answer choices: (1) - Atoms of an element (2) - Molecules of an element (3) - Molecules of a compound (4) - Ions of an element (5) - Mixture of molecules of different compounds (6) - Mixture of atoms of different elements

Figure 4.3 CLDT fundamental section example

Section 3 – Word families

This section tested students' knowledge of related words within a topic area. It was informed by the importance of knowing a range of relevant vocabulary to be able to explain a concept. This section is informed by Lemke (1990) and student awareness of colloquial and scientific language. One "family" of words related to kinetic theory, suitable answers included: *solid, liquid, gas, energy and evaporation*. The second family related to acids and bases and suitable answers included: *hydrochloric, vinegar, neutral and pH.* One mark was awarded for each topic related word up to a maximum of 15 words for each topic. The total possible mark for this section was 30. This represents a substantial proportion of the total marks available (30/81) although it is assessing two different chemical topics.

Section 4 - Symbolic

This section explored students' understandings of symbolic chemical language (Johnstone, 1991; Taber, 2013). The section contained five symbolic representations that tested understanding of chemical formulae (Table 4.6). Students were presented with two similar symbolic representations such as *Br_2 and 2Br* and asked to state whether the two representations had equivalent meaning or not. One mark was awarded for each correct answer with a maximum score of 5.

Question	Equivalent?	Required understanding
NaCl (l) and NaCl (aq)	no	Difference between state symbols (l) and (aq) and liquids and solutions.
H_2O and OH_2	yes	Order of symbols is not significant.
C_2H_6 and CH_3CH_3	yes	Total number of atoms of each element is the same.
Br_2 and 2Br	no	Difference between one diatomic molecule and two atoms of an element.
Co and CO	no	Understanding of the importance of lower and upper case letters in element symbols.

Table 4.6 Questions in the symbolic section of the CLDT

Section 5 – Non-technical

This section presented 10 non-technical words in a multiple choice scientific context. One answer was selected from four alternatives. Figure 4.4 shows the question for *weak*.

(2) What is the meaning of the word "weak" in the following sentence.

"A buffer is normally a mixture of a ***weak*** *acid and its conjugate base"*

A. The acid partially dissociates.

B. The acid fully dissociates.

C. It is a dilute solution.

D. The attractions between the acid molecules are not strong.

Figure 4.4 CLDT non-technical section question for *weak*

This section was informed by Cassels and Johnstone (1985) and Pickersgill and Lock (1991) and challenges of dual meaning vocabulary (Jasien, 2013). Four "red or amber" words were selected from the CLDT pilot (Chapter 4, Section 4.8.1, p. 105) that were relevant to the Foundation chemistry course. These were *reduction, spontaneous, salt and contract. Complex* was also selected to see whether student understanding decreased over Year 0 as reported in the pilot study (Section 4.8.2). *Spontaneous, contract* and *complex* were identified as problematic by Cassels and Johnstone (1985). Five further new non-technical words with dual meaning were included. These words were *solution, weak, cell, saturated* and *neutral.* Misunderstandings of *neutral* were investigated by Jasien (2013). These words were chosen because they are used frequently during Year 0 and two teaching activities (multiple contexts, weeks 13 and 19) focus on the words *weak* and *saturated* (Chapter 3, Section 3.3, p. 85). One mark was awarded for each correct answer with a maximum mark of 10 for this section.

Section 6 – Word choice

This section tested students' awareness of scientific and academic vocabulary. Each question was structured with a key word highlighted in bold (Figure 4.5).

Section 5 – Word choice

The quality of a piece of written work can be greatly enhanced by the choice of words used. The use of more academic and scientific words can improve your writing style and its readability.

Replace the highlighted word or phrase in the following sentences with a more appropriate scientific word or phrase. For example;

- A **solid** formed in the solution in the test tube at the end of experiment.

- A **precipitate** formed in the solution in the test tube at the end of experiment.

(i) When calcium carbonate is heated to a high temperature it **breaks down** into calcium oxide and carbon dioxide.

Figure 4.5 CLDT word choice section question for *decomposes*

Students suggested an alternative word such as *decomposes* for *breaks down* or *combustion* instead of *burning*. Table 4.7 lists the key words included. This section was informed by challenges of understanding and knowledge of colloquial and scientific language Lemke (1990). Ten questions were included, each worth one mark, creating a total of ten marks for this section.

Key word/phrase	Answer	Comments
does not dissolve	insoluble	May be confused with *immiscible*.
breaks down	decomposes	*Disintegrates* possible but not accepted.
makes	synthesis	*Production* accepted as an alternative
separates	dissociates	Splits may be used but not a suitably scientific answer.
ended	terminated	*Finished* possible but not a suitably scientific answer.
does not mix	immiscible	May be confused with *insoluble*.
did not react	inert	*Was unreactive* also possible.
started	initiated	*Commenced* may be used but not a suitable scientific answer.
burning	combustion	*Reacted* possible but not specific.
gives out heat	exothermic	Regularly used during Year 0. May be confused with endothermic.

Table 4.7 CLDT word choice section key words and phrases

Table 4.8 summarises the mark allocation for each CLDT section.

Section	Scoring	Total
Affixes	1 mark for each correct answer	20
Fundamentals	1 mark for each correct answer	6
Word choice	1 mark for each relevant word	30
Symbolic	1 mark for each correct answer	5
Non-technical	1 mark for each correct answer	10
Word choice	1 mark for each correct answer	10
Total score		81

Table 4.8 CLDT mark allocation by section

The students responded to the test hard-copy format in October 2013. They responded to the same test in December 2013. An online version of the test was prepared for May 2014 which contained exactly the same questions as the hard-copy version. The online version was developed so that the tool could be used by students to provide immediate feedback and guide them to support materials.

The online version adapted the hard-copy questions in these ways: the affixes section was a “drag and drop” task. The students were presented with an affix and selected the correct meaning in the table (Figure 4.6).

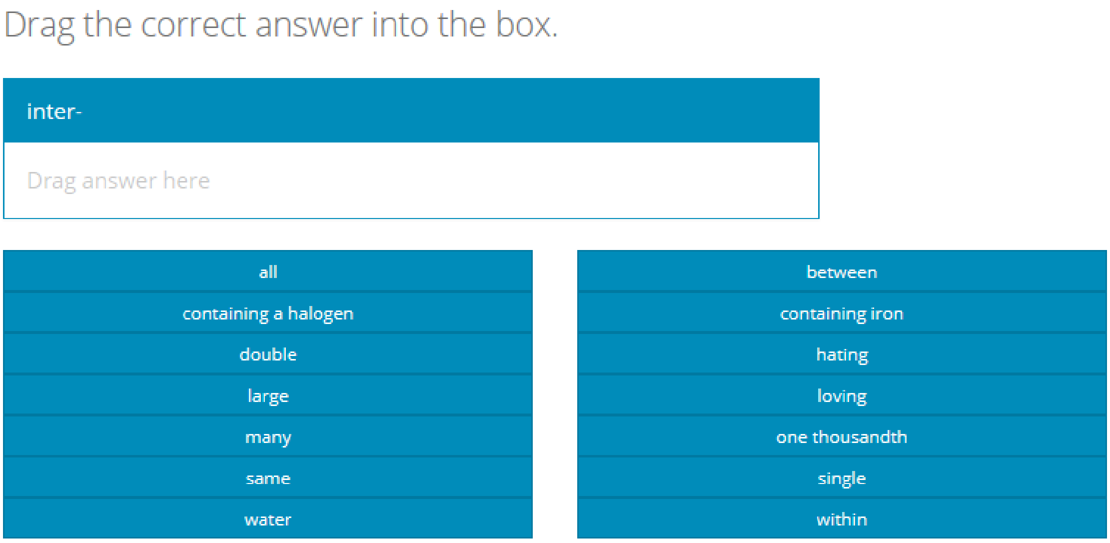


Figure 4.6 Affixes section of the online CLDT

Fundamentals section displayed diagrammatic representations and students selected their answer from the list provided (Figure 4.7).

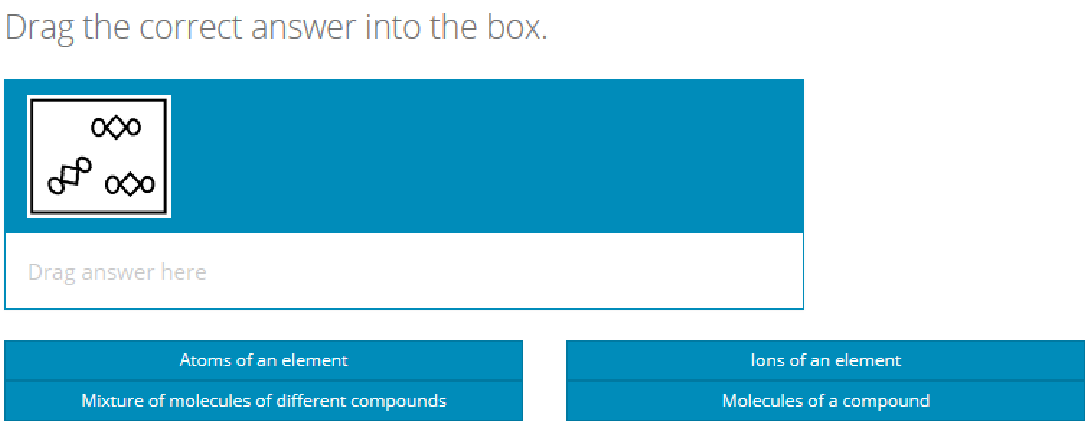


Figure 4.7 Fundamentals section of the online CLDT

In the word family section, students were presented with the chemical topic and given five minutes to enter as many related words they could think of up to a maximum score of 15 (Figure 4.8).

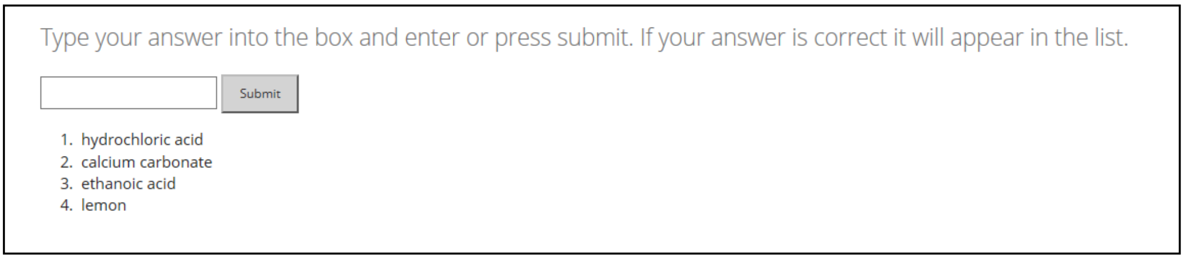


Figure 4.8 CLDT online acid and bases word family example

Symbolic section presented each question, asking if the terms shown were equivalent representations. The students selected “yes”, “no” or “don’t know” (Figure 4.9).

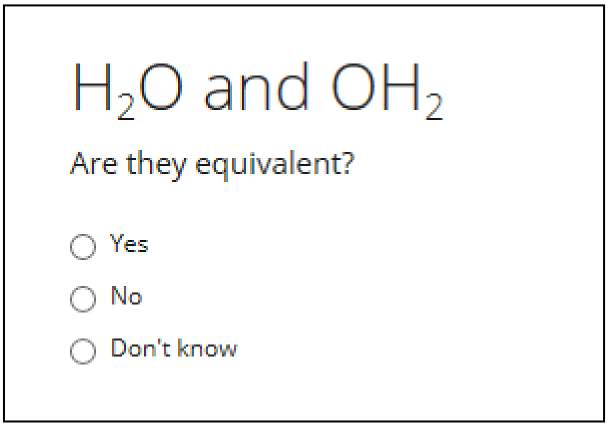


Figure 4.9 Online CLDT symbolic section example

The 2014/15 academic year students responded to the online test in October 2014. This group repeated the test in December 2014 and May 2015.

4.9 Statistical Analysis

CLDT data were collected to reveal in what ways chemical language comprehension ability quantitatively impacted on potential undergraduates’ outcomes and success (Research Question 1, Chapter 1, Section 1.4.1, p. 24). Quantitative data was also collected to indicate the extent to which potential undergraduates’ understanding of chemical language developed during Year 0 (Research Question 2). CLDT data were entered into Microsoft Office Excel® software. Data were divided into sub-groups (Chapter 5, Section 5.3.1, p. 140) for comparison, and the following descriptive statistical analyses were undertaken:

Two-tailed t-tests were carried out to test for significant differences between the scores for the ‘above 40’ and ‘below 40’ student sub-groups (Chapter 5, Section 5.3.1 p. 140).

The t-test is a test of whether a random sample is from two identical unknown populations, *i.e*. values are from populations having equal means and equal variances (Nelson, 2004). Two tailed t-tests were used to allow for the possibility that the teaching activities may have produced a positive or a negative effect.

Chi-squared analysis was carried out to test for significant differences between the responses of the ‘above 40’ and ‘below 40’ student sub-groups to individual items within the symbolic and sections of the CLDT (Chapter 5 Section 5.4 p. 143). The chi-squared test is a test of goodness of fit of a set of observations to a theoretical discrete distribution (Nelson, 2004).

Cohen’s d effect size was undertaken to gauge the magnitude of the effect of the teaching activities on the ‘below 40’ and ‘above 40’ student sub-groups (Chapter 5, Section 5.5, p. 153). Cohen’s d can be used when comparing two means and is the difference in the two groups' means divided by the average of their standard deviations. A *d* of 1, indicates that the two groups' means differ by one standard deviation and a *d* of 0.5 indicates that the two groups' means differ by half a standard deviation. A $d = 0.2$ is considered to be a 'small' effect size, 0.5 represents a 'medium' effect size and 0.8 a 'large' effect size (Walker, 2007).

Pearson’s correlation coefficient was used to test for correlations between CLDT scores and chemistry exam results (Chapter 5, Section 5.6, p. 166). Correlation indicates the association between or interdependence of variables, here, two (Nelson, 2004). The correlation coefficient can have a value between -1 and +1. If $r = 1$, the points lie on a straight line of positive slope; if $r = -1$, they lie on a straight line of negative slope. If r is near zero, then there is virtually no linear association (Nelson, 2004).

4.10 Investigating reading comprehension using eye tracker software

A short reading comprehension task was designed to be undertaken using the Mangold Vision® eye tracker system. This task aimed to determine if there were differences in the reading patterns when students are required to read text. The text requires the students to move repeatedly between macroscopic, sub-microscopic and symbolic levels. The task investigated whether there were any changes in student reading patterns during Year 0. Text described the equilibrium that exists with water molecules and was obtained from the A-level chemistry website www.chemguide.co.uk (Clark, 2016).

This source is recommended to students for independent study. Hence, the text represents an authentic piece of text that students may access via a computer. The eye tracker task replicates the study setting of reading from a screen. The text contained terminology that students may have encountered prior to the task such as *acids*, *bases* and *equilibrium* but extended the explanation to include unfamiliar terminology, namely, *ionic product* of water and the effect of temperature on position of equilibrium.

Participants undertook the task in a suite comprising ten individual eye tracker pods. Each pod contained one computer and eye tracker unit. The camera and infra-red optics for detecting gaze were located on the table beneath the screen. The eye tracker hardware used was Eyetech VT2 and the screen size was 21 inches across. Participants could not interact with each other. Prior to being presented with the first slide, students underwent a calibration process for the eye-tracking technology, looking at a dot at different parts of the screen. Once calibrated, students read text on screen and turned off the programme upon completion.

4.10.1 The eye tracker task slides

A short reading comprehension task containing 270 words and symbols was designed comprising four Powerpoint® slides in total. The text related to the conceptual topics acids and bases, equilibria and K_w. The eye tracker task slides are described in terms of their macroscopic, sub-microscopic and symbolic level content. Table 4.9 summarises slides' content in relation to CLDT sections. The kinetic words section is excluded in Table 4.9 because there was no relevant content in the slides corresponding to this CLDT section.

Slide 1 – Task instructions (Figure 4.10)

Instructions for completing the task.

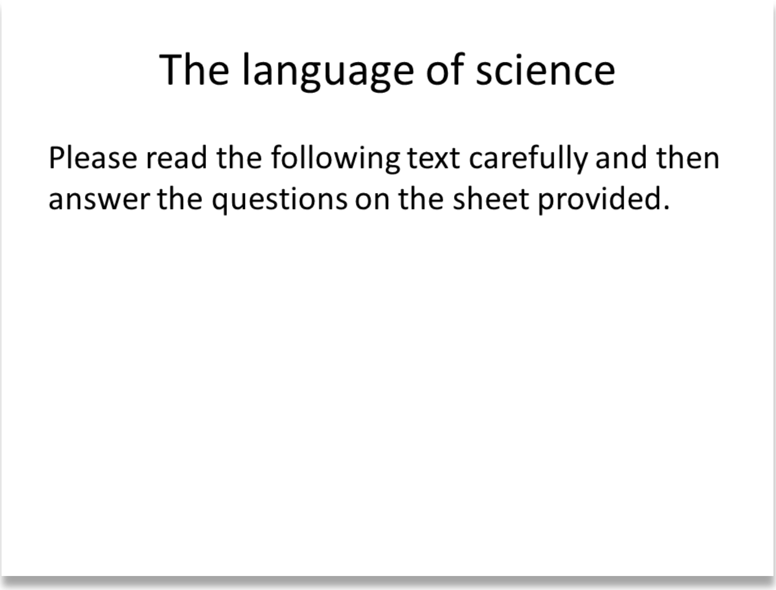


Figure 4.10 Slide 1 – Task instructions

Slide 2 – The important equilibrium in water (Figure 4.11)

The slide title is macroscopic. The first sentence "*water molecules can function as both acids and bases*" is sub-microscopic by referencing "*water molecules*". The next sentence includes three references to *ions* (sub-microscopic). The paragraph then becomes mentions "*a trace of water*" (macroscopic). The second paragraph includes *hydroxonium ion* and *hydroxide ion* which are sub-microscopic terms and then the equation introduces the symbolic level. The final sentence adopts sub-microscopic terms and used symbolic units "*mol* dm^{-3}". The words *acids* and *bases* can be understood on a macroscopic level (*e.g.* low and high pH) and a sub-microscopic level (e.g. as proton donors and acceptors). The usage of these terms in this slide is at the sub-microscopic level.

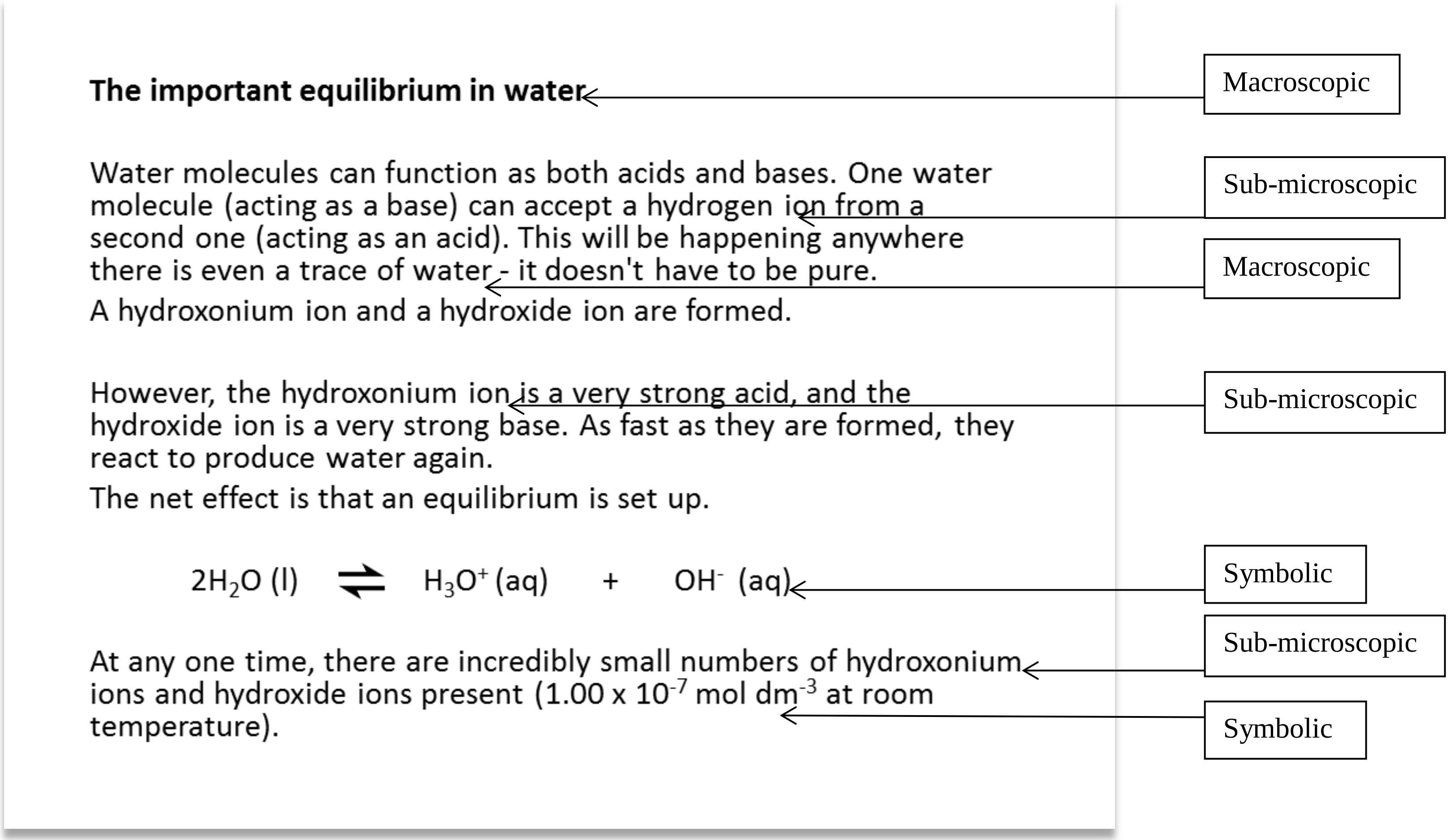


Figure 4.11 Slide 2 – The important equilibrium in water

Slide 3 – Defining the ionic product of water (Figure 4.12)

The title of the slide, the first sentence and the equilibrium constant expression refer to the symbol "K_w". The final paragraph uses macroscopic language "*so little of the water*" when referring to the sub-microscopic process of ionisation.

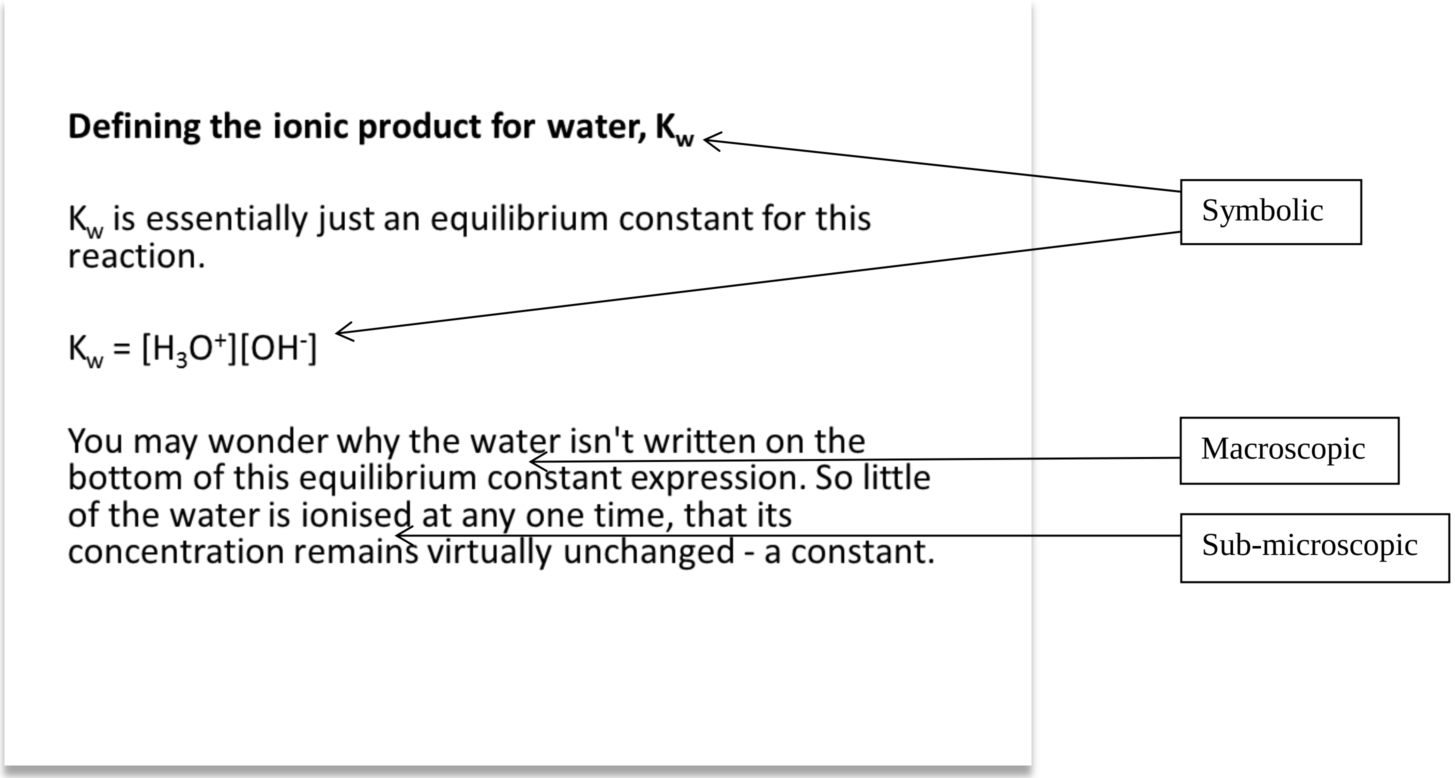


Figure 4.12 Defining the ionic product of water

Slide 4 – The effect of temperature on the value of K_w (Figure 4.13)

The first sentence refers to *hydroxonium ions* and *hydroxide ions* (sub-microscopic) being formed from *water* (macroscopic). The equation operates at the symbolic level. The next paragraph referring to *Le Chatelier's principle* is macroscopic. The final paragraph refers to *hydroxonium ions and hydroxide ions* (sub-microscopic) and K_w (symbolic).

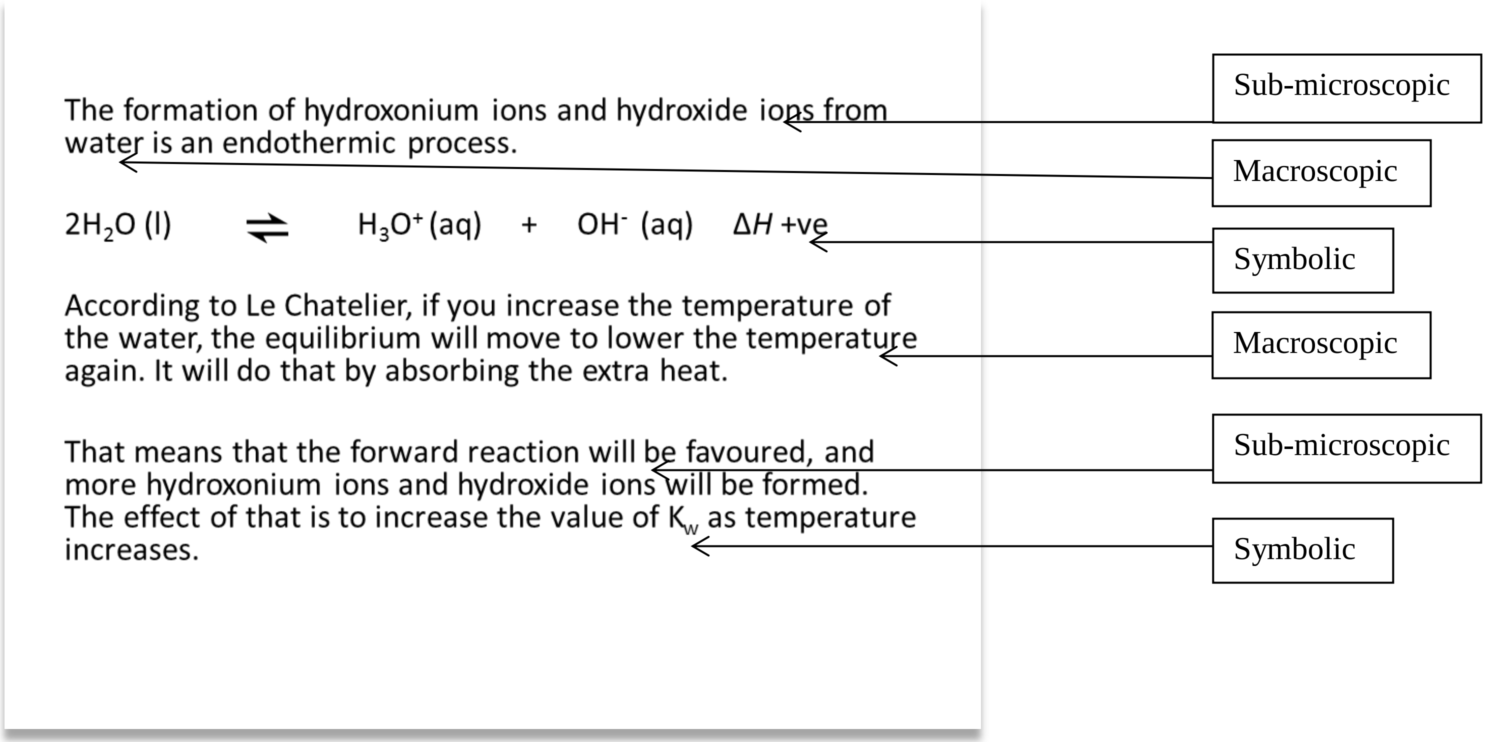


Figure 4.13 The effect of temperature on the value of K_w

Slide	CLDT Section					
	Fundamental	Acid words	Word choice	Non-technical	Symbolic	Affixes
2) The important equilibrium of water	molecule ion	hydrogen ion hydroxonium hydroxide base H_3O^+ OH^-		strong pure equilibrium	$2H_2O$ H_3O^+ OH^- equil (l) (aq) mol dm^{-3}	hydrogen hydroxonium hydroxide equilibrium
3) Defining the ionic product of water	n/a	ionised H_3O^+ OH^-	ionised	concentration expression	K_w = [ ] – concentration H_3O^+ OH^-	equilibrium
4) The effect of temperature	ions	H_3O^+ OH^- ions	endothermic	absorbing equilibrium	$2H_2O$ H_3O^+ OH^- equil (l) (aq) ΔH K_w +ve	endothermic equilibrium

Table 4.9 Eye tracker slide text linked to CDLT content

4.10.2 Analysis

The students completed the eye tracker task twice on 14th November 2014 (five weeks from the start of the foundation course) and on 27th April 2015 (one week before the end). The physical location of the eye tracker suite restricted participation to a sub-set of the student cohort (one out of two classes). The number of participants on each occasion is summarised in Table 4.10. The students voluntarily participated in the task at the end of the timetabled chemistry teaching session.

Participants	November 2014	April 2014
Male	9	8
Female	11	5
Total	20	13

Table 4.10 Summary of the number of participants in the eye tracker study in November and April 2014

Data were analysed using Mangold Vision Analyser® software. Heat maps were produced showing the relative amounts of time participants focused on parts of the screen. Red indicated areas of text where the most time was spent, decreasing from orange to green to blue to purple. The heatmap uses a colour range from 380 nanometers (= dark purple) to 780 nanometers (= dark red). The region that has the most gaze points is colored in dark red. The region that has the least number of gaze points (but still more than 0) is coloured in dark purple. The colours inbetween are evenly distributed, for example the region that is coloured in yellow (580 nanometer, the middle of the colour range) was watched half as much as the dark red regions. Cummulative heat maps were produced for different groups of students. Differences in sample sizes between these groups may affect interpretaion due to individual variability. A larger sample is likely to show more variability than a smaller sample. These data are reported in Chapter 5, Section 5.9, p. 175.

4.11 Semi-structured interviews

Six students were selected to participate in semi-structured interviews. These students were progressing to chemistry, biological science and medicine. They represented a range of ages and mix of gender. Tables 4.11 and 4.12 provide background information, interview dates and academic results for the interview students. Students were ascribed pseudonyms which are used throughout. Three students originated from the UK and had returned to education after a period in work (Kirsty, Ferne, Neil). One student came to the UK sixteen years ago (Linda) and two students (Adam and Evan) had come to the UK after completing Chinese High School.

The students were interviewed during Year 0, then annual interviews up to Year 1 (Ferne, Linda, Evan and Adam), Year 2 (Neil) or Year 3 (Kirsty). Interviews were semi-structured allowing flexibility to pursue topics of interest arising. Interview duration was one hour and comprised two stages: the first stage was a general discussion about students' experience of teaching and learning strategies and wider issues that may be affecting their studies such as housing or financial issues. The second stage involved a "think aloud" task. Students explained a scenario involving kinetic theory, amount of substance and/or the reactivity of benzene (Section 4.11.1). Depending upon the time available, students explained two scenarios at each interview. The interviews took place in classrooms and were recorded by Dictaphone for later transcription (Section 4.11.2).

Student pseudonym	Year commenced studies	Degree route	Qualifications on entry	Age	Interview dates (year of study in brackets)	Academic results	Background
Kirsty	2011	Biomedical sciences	GCSEs (2003) Access to HE programme (2011)	25	November 2011 (0) April 2012 (0) June 2013 (1) August 2014 (2) June 2015 (3)	Year 0 Core Foundation Chemistry 85% Chemical Applications 81% Year 1 overall 55% Year 2 overall 62% Year 3 overall 64%	Local – North East England Previously working full time
Adam	2012	Chemistry	Overseas examination 83% (2013) IELTS[1] 6.0 (2013)	18	November 2012 (0) May 2013 (0) March 2014 (1)	Year 0 Core Foundation Chemistry 60% Chemical Applications 56% Year 1 overall 35%	Educated solely in China
Neil	2012	Medicine	A-levels (2005)	25	November 2012 (0) May 2013 (0) February (1) June 2015 (2)	Year 0 Core Foundation Chemistry 83% Chemical Applications 65% Year 1 overall pass Year 2 overall pass (% not available)	Northern England Previously worked full-time

[1] IELTS – International English Language Test Score

Table 4.11 Interview student summary data

Student pseudonym	Year commenced studies	Degree route	Qualifications on entry	Age	Interview dates (year of study in brackets)	Academic results	Background
Ferne	2013	Biomedical sciences	GCSEs (1993)	36	November 2013 (0) January 2014 (0) March 2014 (0) May 2014 (0) December 2014 (1) June 2015 (1)	Year 0 Core Foundation Chemistry 87% Chemical Applications 74% Year 1 Chemistry for biosciences 41% Year 1 overall 55%	Local – North East England Mother with two young children Previously worked full-time
Linda	2013	Biomedical sciences	Overseas High School certificate (1996)	33	November 2013 (0) February 2014 (0) May 2014 (0) December 2014 (1) June 2015 (1)	Year 0 Core Foundation Chemistry 76% Chemical Applications 67% Year 1 Chemistry for biosciences 40% Year 1 overall 52%	Studied secondary school in Croatia Mother with two young children
Evan	2013	Chemistry	Huikao 87% (2013) IELTS 6.0 (2013)	18	November 2013 (0) February 2014 (0) March 2014 (0) December 2014 (1) June 2015 (1)	Year 0 Core Foundation Chemistry 85% Chemical Applications 81% Year 1 overall 67%	Educated solely in China

[1] IELTS – International English Language Test Score

Table 4.12 Interview student summary data

4.11.1 Scientific scenario model answers

This section describes the "expert chemist" responses sought for the kinetic theory, amount of substance and benzene scenarios.

Scenario 1 – States of matter and kinetic theory

The question posed was "*I blow on a cup of coffee and my glasses steam up – can you explain why?*"

A student demonstrating good/expert chemical knowledge would utilise macroscopic ideas by explaining water turning from a liquid to gas then condensing on the glasses. The response would then adopt sub-microscopic terminology, explaining changes in kinetic energy of the particles causing bonds between molecules to break forming a vapour. These bonds reform as the kinetic energy decreases and molecules cool down on the glasses surface. An expert response may discuss hydrogen bonds between water molecules and how these arise due to differences in electronegativity between hydrogen and oxygen, polarity and the shape of the water molecule. A coherent explanation would not require symbolic language although may be used such as H_2O when referring to water molecules. Kinetic theory and intermolecular bonds were taught in week 3 of the core foundation chemistry course, shapes of molecules were taught in week 4 (Chapter 3, Table 3.1, p. 85).

Scenario 2 – Amount of substance

The question posed was "*10g of lead has fewer atoms in it than 10g of sodium – can you explain why?"*

A student demonstrating good/expert chemical knowledge would utilise macroscopic ideas to explain that the relative atomic mass of lead is higher than that of sodium. Therefore, any given mass of lead will have fewer atoms in it by calculating mass divided by relative atomic mass to determine the amount of substance in moles. An expert response would then utilise sub-microscopic terminology, explaining that lead atoms have a greater mass due to the larger number of protons and neutrons contained within the nucleus. A coherent explanation would not require symbolic language although may be used such as A_r for *Relative Atomic Mass*. Atomic structure and relative atomic mass were taught in week 2 of the core foundation chemistry course.

Scenario 3 – Benzene

The question posed was "*Explain why benzene requires a catalyst to react with bromine whereas cyclohexene and phenol do not*".

This scenario was introduced in academic year 2013/14 and was explained by Ferne and Linda only. This scenario investigates usage of specialist and unfamiliar organic chemistry vocabulary taught in weeks 11 – 15. A student demonstrating good/expert chemical knowledge would utilise sub-microscopic ideas to describe the structure of benzene with a ring of delocalised π-bond electrons. The ring structure redistributes electron density so a dipole in a bromine molecule cannot be induced. The ring is said to be "deactivated" as it will not react with bromine. In cyclohexene, the carbon - carbon double bond has high electron density that induces a dipole in the bromine molecule resulting in a reaction. Lone pairs of electrons on the oxygen atom of phenol join the delocalised π-bond electrons in the ring increasing the electron density. The ring is activated. A coherent explanation would not require symbolic language although may be used when referring to specific electrophiles such as "Br^+". A dipole is induced in the bromine molecule resulting in a reaction. Structure and reactivity of benzene was taught in weeks 11- 13 of the Advanced Chemistry course.

4.11.2 Transcription

Careful consideration was given to transcribing the interviews (Bryman 2008). Transcription was a two stage process. Post-interview, an initial transcription of the interview was prepared without detail but with comments (Figure 4.14). Second stage transcription involved content analysis for language usage and communication strategies (Figure 4.15) using the following protocols. Full transcripts of scientific scenarios are presented in Appendices 1 to 14.

i) Punctuation

Spoken sentences were appropriately punctuated with commas, full-stops, including the use of "?" and "!".

ii) Spellings

Attention was paid to student word usage, including accurate use of spoken terminology e.g. *molecule* and *molecular*.

No no I can't just speak it out

This is what I find hard

Starts drawing

So this represents three pi bonds so if you've got sigma = single pi. Single is the filling in the pi. This is delocalised electrons – 3 bonds delocalised. How do you draw that – I can't do 3d. this kind of like – big cloud haven't yer underneath and above. Its so crap – I want a burger. This is an electron cloud moving around (would call it that) and you don't have one area of higher electronegativity (incorrect term) – see I'm still getting this into my head you know. It isn't in there yet not completely – help me out.

Good use of some terms and then incorrect use of electronegativity

What do you mean there isn't a higher electronegativity?

So you can't induce a dipole. Bit of a mess. So you've got one double bond in cyclohexane – I'm not explaining this very well. Hexene or hexane? – hexene.

Realises error and corrects

This double bond – a species coming along – I don't know I go blank – I'll be alright in an exam because you won't be asking us.

Delocalised cloud – how does it relate to the bromine molecule?

What was I reading about electrons and how they move about and the difference between an orbit and orbital. In an s orbital it can be anywhere. The electron can be pretty much anywhere but here you can't have that – I'm rubbish. I know I'm not I just can't explain it which is part of the problem

Figure 4.14 Excerpt from a student interview showing initial transcription

iii) Hesitation and pauses

Hesitation is a significant occurrence in interviewees' explanation and uncertainty. Brief pauses when an interviewee is sounding out syllables in a word are indicated with a dash (-) *e.g.* e-lec-tron. Significant pauses are indicated with the letter "p" and a number indicating the duration in brackets, for example a two second pause is shown as (p2).

iv) Emphasis and intonations

Significant changes in tone and emphasis are recorded as follows:

- if something was quietly spoken compared to the rest of the passage then font size 8 was used e.g. "the bromine molecule, is it a molecule? Yep, comes over here".

- emphasised words are shown in bold *e.g*. the number of **moles** is less.

- intonations are highlighted with italicised comments in brackets e.g. (*joking*).

v) Interjections

Interruptions of one speaker by another were indicated by ellipses at the end of the preceding sentence (…).

vi) Slang and colloquial language

Slang and colloquial language is transcribed verbatim. Explanation is provided in the left margin for general English or right margin for scientific English.

vii) General English

Incorrect use of general English is highlighted in green and a correction provided in the left margin.

viii) Comment numbers

For reference purposes, comment numbers are assigned and shown on the left of the page.

4.11.3 Data analysis

Interview data analysis was undertaken in terms of chemical language usage to identify emerging themes. The data were interrogated using an organising framework (Barbour 2014) that identified overall correct and incorrect chemical language usage. This resulted in themes being identified inductively from the data (Denzin and Lincoln, 1994) corresponding to Johnstone's triplet (Johnstone, 1991), chemical interlanguage (Chapter 2, Section 2.10.2, p. 75) and linguistic demand in multiple dimensions (Chapter 7, Section 7.5, p. 224). Data were subsequently reanalysed for macroscopic, sub-microscopic and symbolic language usage, transitionary language usage and interlanguage. Particular instances of language usage were identified and explored between interviews by the same student over time and also for different students. Correct use of chemical language (CCL) was highlighted in blue. The first use of a chemistry or scientific word was scored "1". Subsequent use of the same term was not scored again unless used in a new context, *e.g. mass* and then *relative atomic mass*. Correct use of a term was scored "1" even if the overall statement was incorrect. For example in the phrase, "*the molar mass of lead is less than sodium*" the words *molar* and *mass* would each score 1 because *molar mass* is the correct term to use even though the statement is incorrect. Correct usage was not scored if the student repeated chemical language that had first been used by the interviewer.

Incorrect chemical language (ICL) was highlighted in yellow. The first use of a chemistry or scientific word incorrectly was scored "1" and subsequent usage of the same term was not scored again. For example, in the phrase "*the relative molecular mass of lead is greater than sodium*". The word "*molecular*" would score 1. In this phrase the words *relative* and *mass* are correct so would score CCL2. If a word was used incorrectly and correctly within one interview then it would score 1 in both categories.

Passages relating to a particular scenario were also rated to indicate interviewees' level of confidence from 1 (low) to 5 (high) e.g. CR (confidence rating) 2. The total score is recorded in a box at the start of each interview.

States of matter CR2 CCL5 ICL1

Out of a total of twenty eight interviews two were joint, with two students present at the same time (Ferne and Linda, May 2014, Appendix 3; Linda and Nina, November 2013, Appendix 5). This occurred because the students were available at that time and this helped participation. In this situation, individual coding scores were assigned.

Data were systematically analysed and coded for the use of macroscopic, sub-microscopic and symbolic language and informed the findings discussed in Chapter 6 (p. 180). Table 6.1 (p. 183), for example, shows the usage of significant sub-microscopic words by students in the states of matter scenario. Comments were added to the transcript right-hand margin to highlight points of interest such as possible instances of chemical interlanguage. After this second stage, transcription Figure 4.14 excerpt now appears as shown in Figure 4.15.

4 F No, no I can't just speak it out. This is what I find hard (Starts drawing). Not very good at drawing can you tell? So this represents three pi bonds. So if you've got sigma equals single pi. Single is the filling in the pi or the patty in the burger but I thought the pie analogy sounded quite good. This is delocalised electrons – 3 bonds delocalised. How do you draw that? I can't do 3d. This kind of like big cloud haven't yet underneath and above (laughter). It's so crap. I want a burger but it doesn't really relate to that. This is an electron would you call it an electron cloud? So an electron cloud moving around and you don't have one area of higher electronegativity. See I'm still getting this into my head you know. It isn't in there yet not completely. Help me out.

5 I What do you mean there isn't a higher electronegativity?

6 F So you can't induce a dipole. Bit of a mess. So you've got one double bond in cyclohexane – I'm not explaining this very well. Hexene or hexane? Hexane.

7 I Really? Double bond, double…

8 F Yea yea sorry, I think I've written that on my sheet mind, hexane. Yea, this double bond (p1). So you've got something coming along, a species coming along. I don't know I go blank. I'll be alright in an exam if you ask us, because you won't be asking us (laughs).

9 I Structre there, so you've the delocalised electron cloud there – how does it relate to the bromine molecule? Why will the bromine molecule not react with that one?

10 F (p1) What was I reading (p2) about electrons and how they move about and you cannot, it was the difference between an orbits and orbitals. So in an orbital then the electron in a (p1) and (faint laughing). In an s orbital it can be anywhere within it. I see this like that as well that the electron can be pretty much anywhere but here you can't have that, it's fixed and oooh, I don't know, I'm sorry. I'm rubbish.

11 I No you're not at all.

12 F I know I'm not, I just can't explain it which is part of the problem.

13 I Well I think we are kind of going to a bit of tangent really to actually the point. So you've described the structure of benzene…

Transitional understanding

Developing analogies

Incorrect term – confused with electron density hence reference to inducing a dipole

Confusing chemical language

Ferne is losing her way here

Benzene

CR1 CL14 ICL4

Figure 4.15 Second stage transcription of an excerpt of a student interview

A single occurrence of language usage was considered noteworthy of reporting. Discussions would progress within a single interview resulting in different words being used. Instances of students' self-correcting chemical language usage, with or without prompting by the interviewer, occurred on occasions and were noted. These were still scored as correct or incorrect as appropriate. Instances of similar patterns of language usage by students in subsequent interviews were identified as were trends in usage.

This evidence supported themes of transitionary language and Chemical Interlanguage (Table 6.2, p. 201 for example). Evidence for difficulties presented by particular words such as *electronegative* or *molar mass* supported the development of ideas of linguistic demand in multiple dimensions (Chapter 7, Section 7.5, p. 224).

4.12 Summary

This chapter provided a research timeline and explained how the methods adopted addressed the research questions. It described the design and development of the CLDT and eye tracker study. The protocols followed for the interview students were explained, and sampling and ethical considerations were discussed. The next chapter discusses CLDT results.

Chapter 5

Findings from the Chemical Language Diagnostic Test and Eye Tracker Data

5.1 Introduction

This chapter presents data collected from students taking the chemical language diagnostic test (CLDT) (Section 5.2). The CLDT sections and scoring are described in Chapter 4, Section 4.8.3, p. 111 and the CLDT is available in Appendix 16. Section 5.9 presents data from students whose reading patterns were investigated using eye tracker software. These data are used to help identify specific language difficulties. The chapter begins by presenting background data for students of academic year 2013/14 (AY2) and academic year 2014/15 (AY3). These data provide contextual detail referred to throughout. The formation of two sub-groups based on performance in the October 2013/14 CLDT is described in Section 5.3.1. The performance of the two sub-groups in the October 2013/14 CLDT (October 2013/14) is explored in Section 5.4. The AY2 and AY3 students repeated the language diagnostic test in December 2013/14 and May 2014/15, allowing tracking of progress through Year 0, explored in Section 5.3. Statistical techniques have been applied to investigate differences in performance between sub-groups. Correlations between student performance in the CLDT and their academic performance is examined in Section 5.6. Individual progress of students who performed poorly in the initial CLDT is explored in Section 5.7.

5.2 The student cohorts

Table 5.1 presents background data relating to two cohorts studying foundation chemistry named “AY2” (Academic Year 2013-2014) and “AY3” (Academic Year 2014-2015). These two cohorts are combined to form “AY23”. Locus of previous education refers to where the student received their formal education. Background refers to the individuals’ circumstances prior to joining the Foundation Centre. These data indicate that AY23 student cohorts are diverse. In general, potential undergraduates received prior education with varying degrees of success. For example, eleven students were admitted to Year 0 with GCSE (or equivalent) as their highest qualifications. GCSEs (General Certificate of Secondary Education) are the standard school qualifications obtained by students aged 15 to 16 in the UK. Fifty two (60%) students were returning to education after working for between two and twenty years. These students were employed in roles including: bus driver, lawyer, logistic manager, soldier, merchant navy seaman and shop assistant. Twelve students (14%) were returning to education from full-time family responsibilities and twenty two (26%) students came directly from full-time education. Eleven of these students were international, seven were students participating in the Gateway to Medicine[6] programme and four were "conversion" students. Conversion students have recently completed A-levels (or equivalent qualifications) but require different subjects for their chosen degree programme such as chemistry to study a biological sciences degree. Potential undergraduates have reasons for participation such as; a desire for a professional career, a career change, making good educational deficits, setting an example to family and changes in family circumstances. Some potential undergraduates' compulsory education was disrupted by life events such as bereavement, challenging home situation or poor health.

AY23 is 65% male and 35% female. This gender imbalance may reflect the range of degree programmes such as computer science, engineering, physics which tend to attract more male students (Hill, Corbett & St Rose, 2010). Family responsibilities may prohibit mature female students from applying, although social science degree programmes at Year 0 contain a higher proportion of female students. AY23 includes seven female and five male students with children. These students participate in Year 0 to achieve professional status that will provide sound financial support for their families and set a positive example to their children.

[6] The Gateway to Medicine programme selects A-level students in the North East of England that show potential to be doctors and fulfil specific widening participation criteria such as low socio economic group or first generation participation in Higher Education.

Cohort	AY2			AY3			AY23 – Combined cohort		
Locus of previous education[1]	UK	International	Total	UK	International	Total	UK	International	Total
Background									
Work	26 (65) [2]	2 (25)	28 (58)	23 (72)	1 (17)	24 (63)	49 (68)	3 (21)	52 (60)
Family	6 (15)	0	6 (13)	6 (19)	0	6 (16)	12 (17)	0	12 (14)
Direct from education	8 (20)	6 (75)	14 (29)	3 (9)	5 (83)	8 (21)	11 (15)	11 (79)	22 (26)
Total	**40**	**8**	**48**	**32**	**6**	**38**	**72**	**14**	**86**
Gender									
Male	28 (70)	5 (63)	33 (69)	19 (59)	4 (67)	23 (61)	47 (65)	9 (64)	56 (65)
Female	12 (30)	3 (37)	15 (31)	13 (41)	2 (33)	15 (39)	25 (35)	5 (36)	30 (35)
Age									
<21	5 (13)	2 (25)	7 (15)	5 (16)	3 (50)	8 (21)	10 (14)	5 (36)	15 (18)
21-25	17 (43)	5 (63)	22 (46)	14 (44)	3 (50)	17 (45)	31 (43)	8 (57)	39 (45)
26-30	12 (30)	1 (12)	13 (27)	7 (22)	0	7 (18)	19 (26)	1 (7)	20 (23)
31+	6 (14)	0	6 (12)	6 (18)	0	6 (16)	12 (17)	0	12 (14)
Mean	26.2	23.2	24.9	26.8	21.3	25.1	26.4	22.7	25.0
Standard deviation	5.8	3.9	5.2	6.1	3.4	5.1	5.9	3.6	5.1
Planned degree									
Biological/Biomedical science	14 (35)	2 (25)	16 (33)	6 (19)	1 (17)	7 (18)	20 (27)	3 (21)	23 (27)
Chemistry	2 (5)	1 (13)	3 (6)	1 (3)	0	1 (3)	3 (4)	1 (7)	4 (5)
Computer Science	3 (8)	2 (25)	5 (10)	2 (6)	0	2 (6)	5 (7)	2 (14)	7 (8)
Earth Science	2 (5)	3 (37)	5 (10)	2 (6)	2 (33)	4 (11)	4 (5)	5 (37)	9 (10)
Engineering	4 (10)	0	4 (8)	2 (6)	0	2 (6)	6 (9)	0	6 (7)
Medicine	6 (15)	0	6 (12)	5 (16)	0	5 (12)	11 (15)	0	11 (13)
Pharmacy	2 (5)	0	2 (4)	10 (32)	2 (33)	12 (32)	12 (18)	2 (14)	14 (16)
Physics	7 (17)	0	7 (17)	4 (12)	1 (17)	5 (12)	11 (15)	1 (7)	12 (14)

[1] See text for explanation [2] % in parentheses

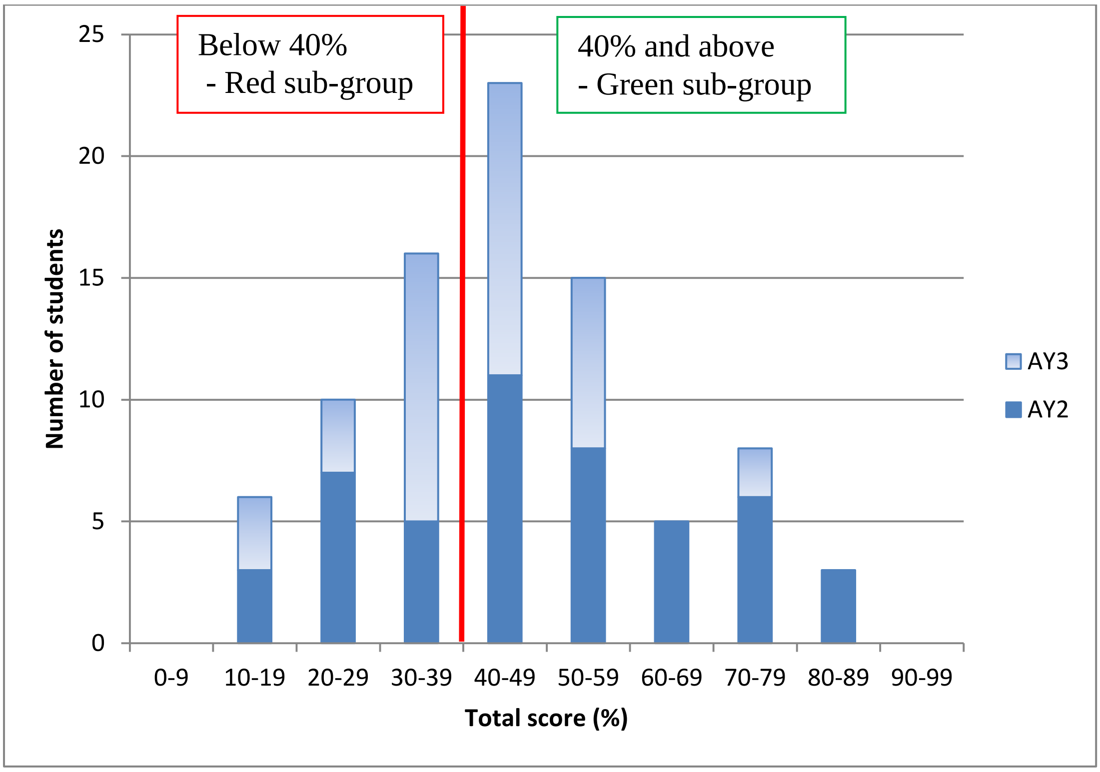
Table 5.1 Background information relating to AY2, AY3 and AY23 student cohorts

Fifteen AY23 students (18%) were aged under twenty one at the start of Year 0. These are international students and students on the Gateway to Medicine programme. Fifty nine AY23 students (68%) were aged 21 to 30. Most joined Year 0 from employment but wish to enhance their employment status. Twelve AY23 students (14%) were over thirty years old. Members of this sub-group often have family responsibilities.

Fifteen AY23 students (18%) were international students. These students, who achieved good results in their home country, enrolled on Year 0 because their qualifications are unsuitable for direct entry in to Year 1. This sub-group includes students from: Greece, Saudi Arabia, South Korea, Myanmar and one student from Egypt. Fifty three AY23 students (63%) aimed to pursue degree programmes for which knowledge of chemistry is a pre-requisite. These routes are: chemistry, biological and biomedical science, pharmacy and medicine.

5.3 AY23 initial understandings of chemical language

Figure 5.1 presents AY23 CLDT results. These provide baseline data of students' chemical language understanding.



n = 86 (AY2 = 48, AY3 = 38)

Figure 5.1 October CLDT data for AY23

The scores fit a normal distribution curve (Anderson-Darling value = 0.473, p = 0.23). The normal probability plot is shown in Figure 5.2. The median score is 44.0. The mean score is 44.3. The standard deviation is 18.1 suggesting initial chemical language understanding is varied. This reflects the diverse nature of Year 0 cohorts and the wide range of knowledge and prior experience of chemistry.

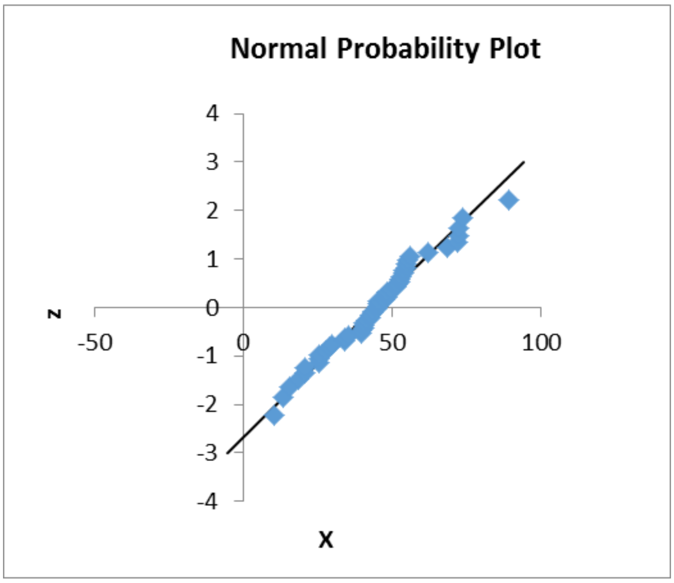


Figure 5.2 October CLDT data normal probability plot

Eleven AY23 students (15%) achieved scores greater than 70%. These scores imply students had good chemical language understanding. This sub-group consisted of three UK students who had recently studied A-level Chemistry and were on the Gateway to Medicine programme, four UK students aged between 21 to 25 who had previously studied A-level sciences, three UK students aged 21 to 25 and one home schooled student from Hong Kong with excellent English language skills.

5.3.1 Creating "red" and "green" sub-groups

For reporting, AY23 was divided into two sub-groups determined by baseline CLDT data. 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 40%. Thirty-one students (36%) of AY23 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 chemical language use. Fifty five students (64%) scored 40% or more and are referred to as the "green" group. Consideration was given to setting the threshold at 50% which would have brought a further twenty three students into this sub-group or 63% of the cohort. The aim of the study, however, was to focus on progress of the weakest students in the cohort. Therefore, 40% is a suitable threshold for a sub-group comprising the weakest third of the cohort. Twenty three students (27%) scored in the median 40-49% range and six of these students scored 40 – 43%. Therefore, there were some students that were also very close to the 40% threshold. The grouping is not a perfect split but any boundary will always have near misses and 40% is the mark required for an undergraduate pass. For comparisons of CLDT scores across Year 0 (Chapter 5, Section 5.5.1, p. 157) sub-group data was only included for students that completed all three CLDTs in October, December and May. This was 15 Red sub-group students and 37 Green sub-group students.

5.3.2 Baseline chemical language exhibited by "red" sub-group students

Red sub-group students show weakness across all language categories. The lexical based sections of *Acid words*, *Kinetic words* and *Word choice* (Chapter 4, Section 4.8.3, p. 111) seemed particularly challenging. Over 50% of the CLDT score relates to these three sections (Chapter 4, Table 4.8, p. 113). Therefore, low scores in these sections significantly impacts on total score. Red sub-group students suggested between zero and five words associated with acids or kinetic theory. Red sub-group students were unable to provide more scientific alternative words in an example sentence, such as *decomposes* for *break down*, *initiates* for *starts* and *combustion* for *burning*. This reflects weakness in the range of an individual's vocabulary. Although these students scored higher on *Fundamentals* and *Symbolic* sections at 55% and 50% respectively, some items were particularly difficult. For example, in the *Symbolic* section, 75% of Red sub-group students stated that *NaCl(aq)* and *NaCl(l)* were equivalent, in the *Fundamentals* section, ten students scored five or six out of six whilst seven students scored zero or one out of six. This indicates that some students were relatively confident with the meaning of terms such as *atom*, *molecule* and *compound* whilst others were not. The *Non-technical* section had a mean correct score of 42%. Within this section, 78% of students did not know the meaning of *weak* and 89% did not know the meaning of *reduction* in a chemistry context.

5.3.3 Baseline chemical language exhibited by “green” sub-group students

The Green sub-group comprises fifty five students who scored between 40% and 90% in the October CLDT. On the basis of their results, these students are considered to have satisfactory or better knowledge of chemical language at the start of Year 0. In general, the pattern of responses was similar to the red sub-group with the *Acid words, Kinetic words* and *Word choice* sections having the lowest scores. Green sub-group students suggested between three and ten words for the *Acid words* and *Kinetic words* sections indicating a greater awareness of relevant vocabulary compared to the Red sub-group. Responses to individual questions within sections also followed a similar pattern to the Red sub-group. In the *Symbolics* section 49% of Green sub-group students did not recognise H_2O and OH_2 as equivalent and 45% stated that *NaCl(aq)* and *NaCl(l)* were equivalent. In the *Non-technical* words section, 65% of Green sub-group students did not know the meaning of *weak* in a chemistry context and 53% did not know the meaning of *reduction* in a chemistry context.

5.3.4 Red and Green sub-groups background data

Background data for the Red and Green sub-groups are provided in Table 5.2. Gender distribution and mean ages are similar for both sub-groups. The Red sub-group contains eight out of fourteen international students in the whole sample. These eight students had all recently completed formal education. Five were students of Asian origin students and three were from the Middle East.

Proportionally fewer students in the Red sub-group were progressing to medicine (2 out of 11) and physics (2 out of 12). Conversely, proportionally more Red sub-group students were progressing to biological/biomedical sciences (11 out of 23), earth sciences (5 out of 9) and engineering (4 out of 6). In Year 1, exposure to chemistry is most significant in biological and biomedical science and least significant in physics. Knowledge of chemistry is applicable to earth materials and geochemistry modules in earth sciences and modules in thermodynamics and fluid mechanics in engineering.

5.4 Analysis of October CLDT data by language component

This section analyses the October CLDT scores for each section by Red and Green sub-groups. Section 4.8.3 (p. 111) describes the CLDT sections in detail and the CLDT is available in Appendix 16. Figure 5.3 shows October mean scores for the Red and Green sub-groups for the seven sections of the CLDT.

The Red sub-group demonstrated poorer understanding of chemical language across all sections of the CLDT than the Green sub-group. Both sub-groups showed the same trend in scores with the *Word Choice* section having the lowest mean score and the *Fundamentals* section the highest. The *Affixes* section was the only exception with the second highest score for the Green sub-group and fourth highest for the Red sub-group.

Locus of previous education*	Red sub-group AY2	Red sub-group AY3	Red sub-group AY23	Green sub-group AY2	Green sub-group AY3	Green sub-group AY23	Total
UK	10 (45)	13 (55)	22 (31)	30 (61)	19 (39)	49 (69)	72 (84)
Europe	0	0	0	1 (50)	1 (50)	2 (100)	2 (2)
Middle East	2 (67)	1 (33)	3 (75)	1 (100)	0	1 (25)	4 (4)
Asia	2 (40)	3 (60)	5 (71)	2 (100)	0	2 (29)	7 (8)
Africa	0	0	0	0	1 (100)	1 (100)	1 (2)
Total	14 (45)	17 (55)	31 (36)	34 (62)	21 (38)	55 (64)	86
Background*							
Work	8 (42)	11 (58)	19 (37)	20 (60)	13 (40)	33 (63)	52 (60)
Family	2 (50)	2 (50)	4 (33)	4 (50)	4 (50)	8 (67)	12 (14)
Direct from education	4 (50)	4 (50)	8 (36)	10 (71)	4 (29)	14 (64)	22 (26)
Gender							
Male	9 (45)	11 (55)	20 (36)	24 (67)	12 (33)	36 (64)	56 (65)
Female	5 (45)	6 (55)	11 (36)	10 (53)	9 (47)	19 (64)	30 (35)
Age							
<21	2 (40)	3 (60)	5 (33)	5 (50)	5 (50)	10 (67)	15 (17)
21-25	7 (46)	8 (54)	15 (38)	15 (63)	9 (23)	24 (62)	39 (46)
26-30	3 (50)	3 (50)	6 (30)	10 (71)	4 (29)	14 (70)	20 (23)
31+	2 (40)	3 (60)	5 (42)	4 (57)	3 (43)	7 (58)	12 (14)
Mean age	24.4	24.3	24.3	25.1	24.7	24.9	24.8
Standard deviation	4.2	4.8	4.6	4.0	4.3	4.1	4.4
Planned degree route							
Biological/biomedical sciences	6 (54)	5 (46)	11 (48)	10 (83)	2 (17)	12 (52)	23 (27)
Chemistry	1 (100)	0	1 (25)	2 (67)	1 (33)	3 (75)	4 (5)
Computer science	1 (50)	1 (50)	2 (29)	4 (80)	1 (20)	5 (71)	7 (8)
Earth sciences	3 (60)	2 (40)	5 (56)	2 (50)	2 (50)	4 (44)	9 (10)
Engineering	2 (50)	2 (50)	4 (67)	2 (100)	0	2 (33)	6 (7)
Medicine	1 (50)	1 (50)	2 (18)	5 (56)	4 (44)	9 (82)	11 (13)
Pharmacy	0	4 (100)	4 (29)	2 (20)	8 (80)	10 (71)	14 (16)
Physics	0	2 (100)	2 (17)	7 (70)	3 (30)	10 (83)	12 (14)

* See text for explanation

Table 5.2 Background information for the Red and Green student sub-groups

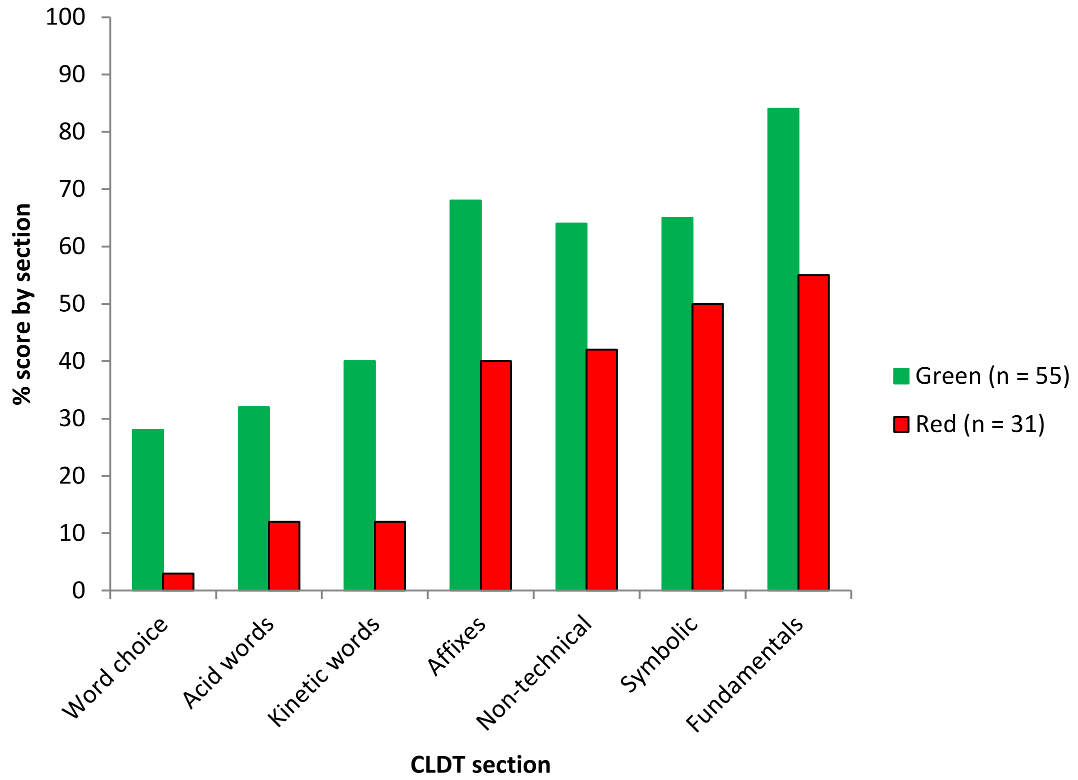


Figure 5.3 Red and Green sub-group mean October CLDT scores (%) by language component

Test section	Green sub-group		Red sub-group		t	p
	Mean score (%)	sd	Mean score (%)	sd		
Word choice	28	20.4	3	6.8	8.0	<0.001
Kinetic words	40	16.8	12	12.1	6.8	<0.001
Affixes	68	17.9	40	21.6	5.7	<0.001
Non-technical	64	18.1	42	20.4	4.6	<0.001
Acid words	32	13.3	12	12.2	4.1	<0.001
Fundamentals	84	20.9	55	33.9	4.1	<0.001
Symbolic	65	23.6	50	17.9	3.4	<0.001

n = 86 sd = standard deviation t = Two tailed t-test p = probability

Grey rows highlight statistically significant items.

Table 5.3 October CLDT sections Statistical data for Red and Green student sub-groups

The *Word choice* section was poorly answered with a mean score of 3% (sd = 6.8) for the Red sub-group and 28% (sd = 20.4) for the Green sub-group. Twenty of the Red sub-group students failed to answer any of the *Word choice* questions correctly. Twelve of these students were UK mature and eight were international students. These students have lexical weakness with poor awareness of chemistry related vocabulary. This weakness may not have been only due to the target word in the question but also the broader language used. For example, one question asks the student to replace the word *making* in the following sentence:

"*7) The first stage of the* ***making*** *of aspirin requires reflux apparatus*."

The words *aspirin, reflux,* and *apparatus* may also generate difficulties demonstrating that words do not exist in isolation but must be understood in context. This is important for corpus linquistics which provides the opportunities to experience words in multiple contexts.

Figure 5.4 shows the mean correct scores for each word in the *Word choice* section for the Red and Green sub-groups. The words *insoluble, decomposes, dissociates* and *terminated* received zero correct response from the Red sub-group. This suggests that the Red sub-group students were not aware of these words and/or did not know their meaning was synonymous with the key word. Around 50% of Green sub-group students correctly answered *exothermic* (52% correct) and *combustion* (48% correct) whilst *insoluble, decomposes, synthesis, dissociates, terminated* and *immiscibl*e scored below 30% correct. Table 5.4 indicates that the scores were statistically significantly different between the two sub-groups for all words in this section. This data suggests that AY23 had limited knowledge of this scientific vocabulary in October.

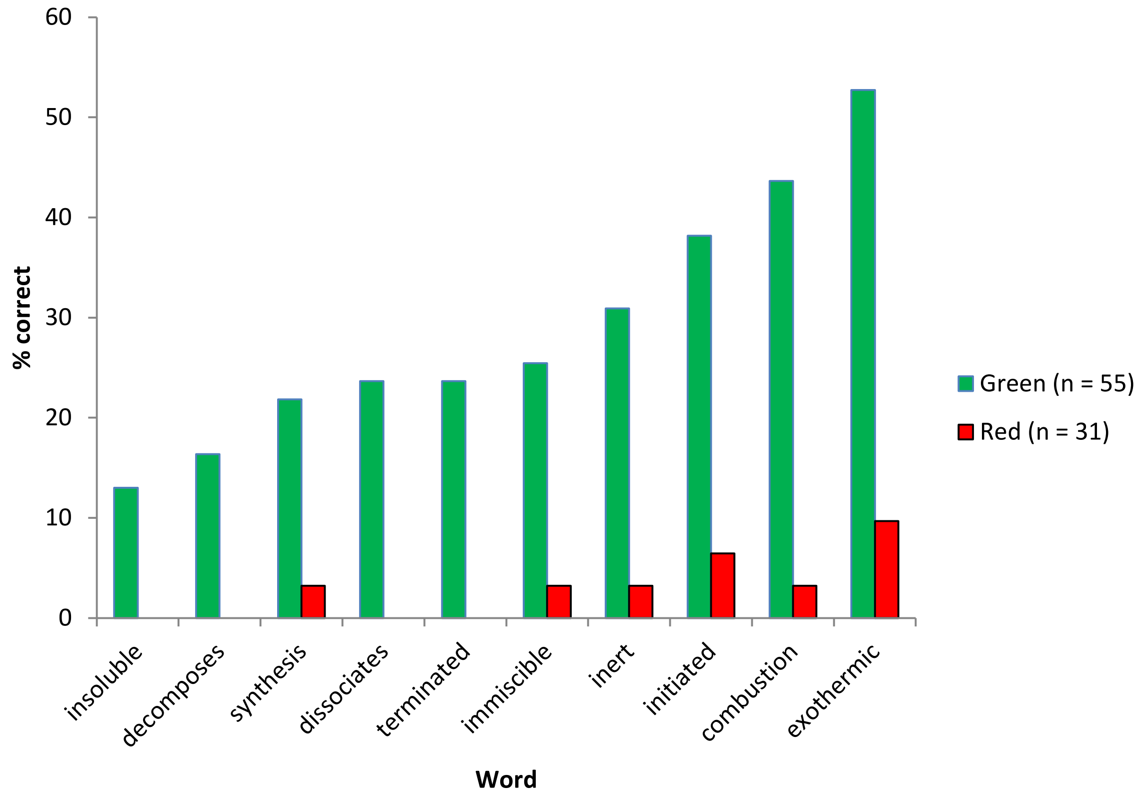


Figure 5.4 Percentage correct response in October for the *Word choice* section for the Red and Green sub-groups

Word	Green sub-group % correct	Red sub-group % correct	χ^2	p
Exothermic	53	10	14.3	<0.001
Combustion	44	3	15.2	<0.001
Initiated	38	6	9.7	0.005>p>0.001
Dissociates	24	0	8.4	0.005>p>0.001
Inert	31	3	8.6	0.005>p>0.001
terminated	24	0	8.4	0.005>p>0.001
Decomposes	16	0	5.9	0.05>p>0.01
Insoluble	13	0	4.0	0.05>p>0.01
Synthesis	22	3	4.5	0.05>p>0.01
Immiscible	25	3	6.1	0.05>p>0.01

n = 86 χ^2 = Chi squared p = probability

Grey rows highlight statistically significant items.

Table 5.4 Statistical significance data for the October CLDT *Word choice* section

The Red sub-group students had a mean score of 12%, or 1.8 words, in both the *Acid words* and *Kinetic words* sections. Six Red sub-group students suggested no relevant words for the *Acid words* section and twelve Red sub-group students suggested no relevant words for the *Kinetic words* section. This indicates that the Red sub-group students had limited knowledge or awareness of topic related vocabulary. Developing meaning is more problematic for these students as they are less likely to comprehend words used to explain a concept. This lack of familiarity with related vocabulary may also explain the observed difficulties with reading comprehension during the eye tracker exercise (Section 5.9, p. 175). The Green sub-group students had a mean score of 32% (4.8 words) for the *Acid words* section and 40% (6 words) for the *Kinetic words* sections. Chi-squared test data show differences were significant p = 0.05 level.

The Red sub-group had a mean score of 40%, or 8 out of 20, for the *Affixes* section whilst the Green sub-group performed significantly higher with a mean score of 68% (13.6 out of 20). In the Red sub-group, eight students scored between zero and five out twenty. Four of these students were international and four were UK mature. This indicates that the Green sub-group had better knowledge of roots of chemical language and are more likely to be able to interpret new unfamiliar vocabulary (Herron, 1996; Wellington and Osborne, 2001; Chapter 2, Section 2.6, p. 58). This is supported by reading comprehension skills demonstrated in the eye tracker task (Section 5.9, p. 175).

In the *Non-technical* word section, the Red sub-group had a mean score of 42%. Eight students scored between zero and three out of ten. Five of these students were international and three were UK mature suggesting that non-technical words were more problematic for international non UK-based students. Five students scored between seven and nine out of 10. Two of these students were international and three were UK mature. This indicates that a minority (16%) of Red sub-group students had a good understanding of non-technical vocabulary.

Figure 5.5 shows data for each word for Red and Green sub-groups. Data indicate that all non-technical words were correctly defined by less than 70% of the Red sub-group with the exception of *complex* (90% mean correct score). *Weak, reduction, solution, cell, saturated, spontaneous and salt* reported correct scores below 50% for the Red sub-group. Sixteen Red sub-group students (52%) scored between zero and two out of seven for these words, indicating that understanding of these words was problematic. Six of these students were international and ten were UK mature. The meaning of *weak* in the question is "*a weak acid that partially dissociates*". This is a specific chemical meaning that is distinct from every day meanings of *feeling weak* (lacking energy), *a weak solution* (dilute) or a *weak joint* (not strong). Therefore, unless students had learnt the correct chemical context previously, they are likely to choose an everyday meaning. The same argument can be applied to *reduction*. The meaning of *reduction* in the question is "*gaining electrons*". This specific chemical meaning is distinct from its everyday meaning of *reduction in size* or *price* (getting smaller) or *reducing a liquid* (boiling to lower the volume). The meaning of *solution* in a chemistry context "*a mixture of a liquid and a dissolved solid*" shares more in common with one of its everyday meaning such as *a sugary solution.* However, 81% of Red sub-group students chose alternative responses of "*A substance that dissolves in a liquid*" (solute) and "*A substance that dissolves a solid*" (solvent). The Green sub-group showed a similar overall trend in mean scores across this section apart from *reduction* and *solution.* The scores for these two words were substantially higher for the Green sub-group indicating greater knowledge of their meaning in a chemistry context.

Complex was correctly answered by 90% of Red sub-group and 100% of Green sub-group students indicating good understanding. The meaning of *complex* in the phrase "*a complex reaction*" is similar to one of its everyday uses. A *complex reaction* involves several stages and *a complex situation* is complicated or involves many different components. The alternative responses for the question were "*the reaction goes to completion*", "*the reaction is slow*" and the "*reaction is simple*". These are not alternative contexts for the meaning of complex such as "*a building complex*" for example. Alternative chemistry contexts for *complex* such as *complex ions* were not tested in this question. Therefore, unlike with *weak*, the alternative responses may be easier to discount. *Complex* is a problematic word identified by Cassels and Johnstone (1985; Table 2.5, p. 51) and was included due to the apparent decrease in understanding in the CLDT pilot (Chapter 4, Section 4.8.2, p. 107). However, the initial result suggests that understanding of *complex* in this context was high in AY23.

Jasien (2010; Chapter 2, Section 2.4, p. 54) identified problematic understanding of *neutral*. *Neutral* was correctly answered by 68% of Red sub-group and 85% of Green sub-group students. This indicates AY23 students have good understanding of *neutral* although 32% of the Red-sub group did not understand the meaning of the word in the context of a *neutral atom*.

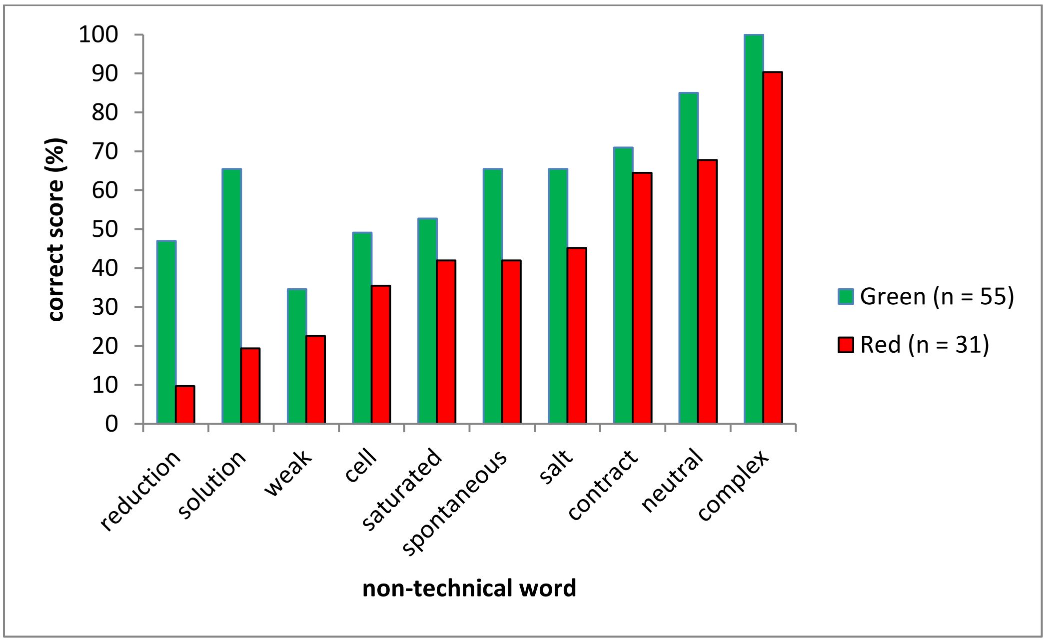


Fig 5.5 Percentage correct response for October *Non-technical* CLDT section by Red and Green sub-groups

Non-technical word	Green sub-group Correct (%)	Red sub-group Correct (%)	χ^2	p
Solution	65	19	17.5	<0.001
Reduction	47	10	11.4	<0.001
Complex	100	90	6.3	0.05>p>0.01
Spontaneous	65	42	5.1	0.05>p>0.01
Salt	65	45	3.9	0.05>p>0.01
Neutral	85	68	3.8	>0.05
Weak	35	23	1.4	>0.1
Saturated	53	42	1.1	>0.1
Contract	71	65	0.6	>0.1
Cell	49	35	1.2	>0.1

n = 86 sd = standard deviation χ^2 = Chi squared p = probability
Grey rows highlight statistically significant items.

Table 5.5 Statistical significance data for October CLDT *Non-technical* word section by Red and Green student sub-groups

The *Symbolic* section had a mean score of 50% (s.d. = 17.9) for the Red sub-group and 65% (s.d.=23.6) for the Green sub-group. Sixteen students scored two or less out of five. Twelve of these students were UK mature and four were international. This indicates that understanding of symbolic language of chemical formulae was problematic for AY23 students. Figure 5.6 shows differences between the individual symbolic language items. *Co*/*CO* was correctly answered by 93% of Red sub-group and 94% of Green sub-group students indicating that most students could correctly interpret upper and lower case letters in element symbols. Br_2 and *2Br* were identified as not equivalent by 68% of Red sub-group and 73% of Green sub-group students. However, precise understanding of the difference between these formulae in terms of a diatomic molecule or two separate atoms cannot be determined from the test. It could also be argued that these two items are equivalent as they represent the same total number of atoms. About two thirds of Red sub-group students and half of Green sub-group students thought that H_2O/OH_2 were not equivalent. This suggests significance was assigned to the order in which the element symbols are presented. About 60% of Red sub-group students thought C_2H_6/CH_3CH_3 were not equivalent indicating they interpret the formulaic representation to illustrate a significant difference. Five Red sub-group students (16%) correctly identified *NaCl(aq)*/*NaCl(l)* as not equivalent. Four of these students were international and one was UK mature. This was significantly different to the Green sub-group (Table 5.6). To answer this item incorrectly, the difference between the state symbols *(aq)* and *(l)* and/or the difference between an aqueous solution and a liquid is not understood. This distinction is not identified by the CLDT.

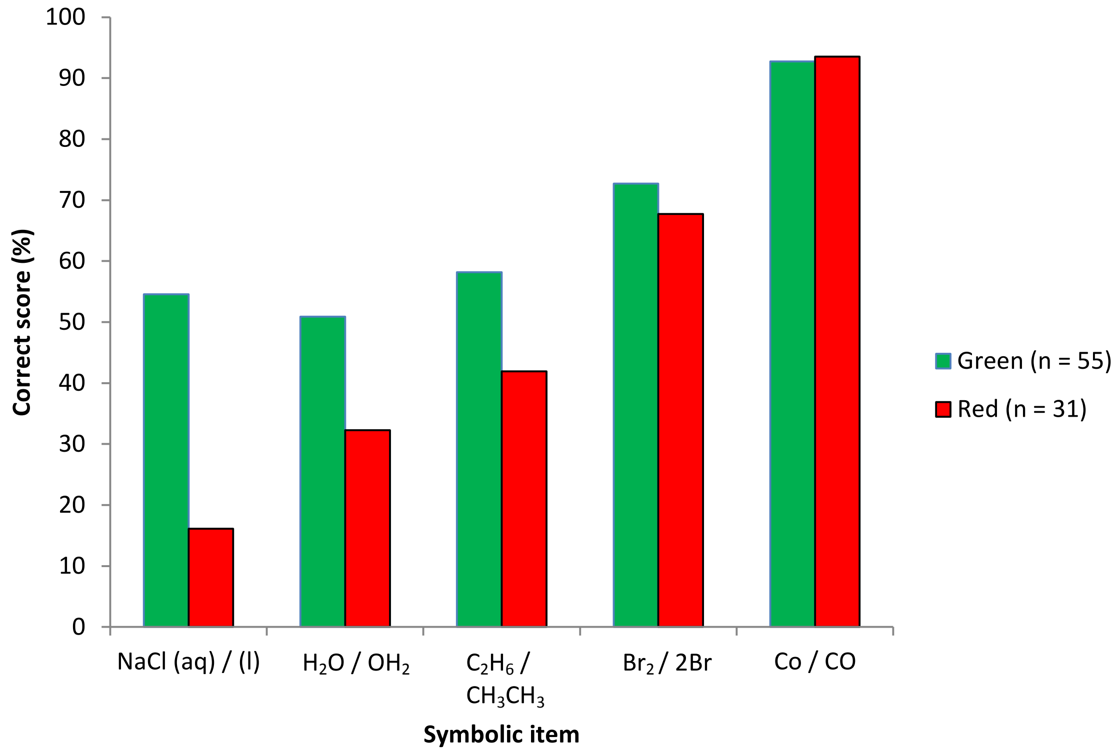


Figure 5.6 Percentage correct response for October *Symbolic* CLDT section for Red and Green sub-groups

Symbolic item	Green sub-group Correct (%)	Red sub-group Correct (%)	χ^2	p
NaCl(aq)/(l)	55	16	13.2	<0.001
H_2O/OH_2	51	32	2.6	>0.1
C_2H_6/CH_3CH_3	58	42	2.3	>0.1
Br_2/2Br	73	68	0.35	>0.5
Co/CO	93	94	0.03	>0.5

n = 86 s.d.= standard deviation χ^2 = Chi squared p= probability

Note: The grey shaded row highlights a statistically significant result.

Table 5.6 Statistical significance data for October CLDT *Symbolic* word section

The Red sub-group reported a mean score of 55% for the *Fundamentals* section. The standard deviation is 33.9 indicating a wide variation in scores. Eleven Red sub-group students showed good understanding of word meanings such as *atom*, *molecule* and *compound* with scores of four or higher out of six. Nine Red sub-group students scored two or less out of six indicating poor understanding of these words. Seven of those students were UK mature and two were international. This section uses less text and may be easier to access for students with weak general language skills compared to other sections.

In summary, the October CLDT data indicates chemical language weaknesses in all sections for AY23, particularly in the lexical based sections of *Word choice*, *Acid words and Kinetic words.* The majority of Red sub-group students answered all sections incorrectly except *Symbolic* (50% correct) and *Fundamentals* (55% correct). The Green sub-group showed greater knowledge of affixes than the Red sub-group. Within sections, both sub-groups showed similar trends in responses although there were some differences in understandings of *reduction, solution, exothermic, combustion and NaCl(l)/(aq).*

5.5 Monitoring chemical language development during Year 0

This section investigates how AY23 responses changed during Year 0. The CLDT was repeated in December (at the end of the first term) and in May (at the end of Year 0). The number of students undertaking the CLDT decreased from 86 in October to 75 in December due to four students withdrawing from the course and seven students being absent from the repeat administration of the CLDT. Fifty two students undertook the test in May. Twenty five students progressing to physics, engineering and computer science degrees do not continue to study chemistry in term 2 (Chapter 1, Section 1.2, p. 23). One student withdrew between December and May. Four students were absent from the repeat administration of the CLDT. Figure 5.9 shows the distribution of total scores during Year 0. The data is normally distributed (December: Anderson-Darling value = 0.513, $p = 0.19$; May: Anderson-Darling value = 0.452, $p = 0.26$). Figures 5.7 and 5.8 report the normal probability plots for December and May CLDT data.

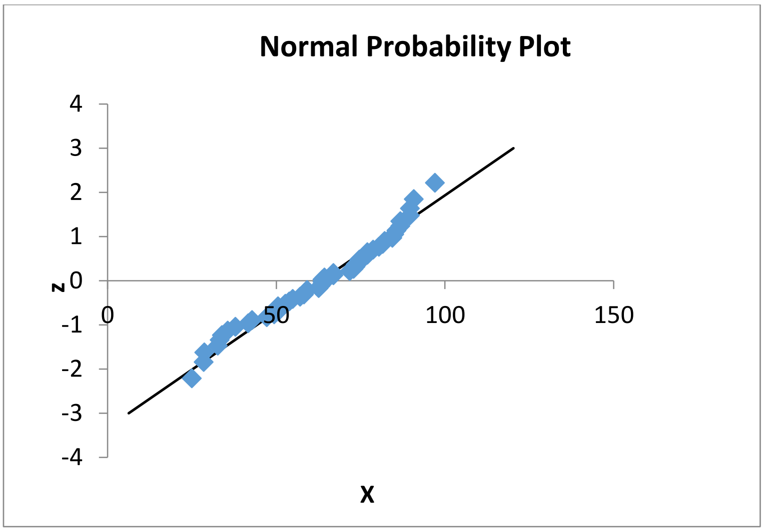


Figure 5.7 December CLDT data normal probability plot

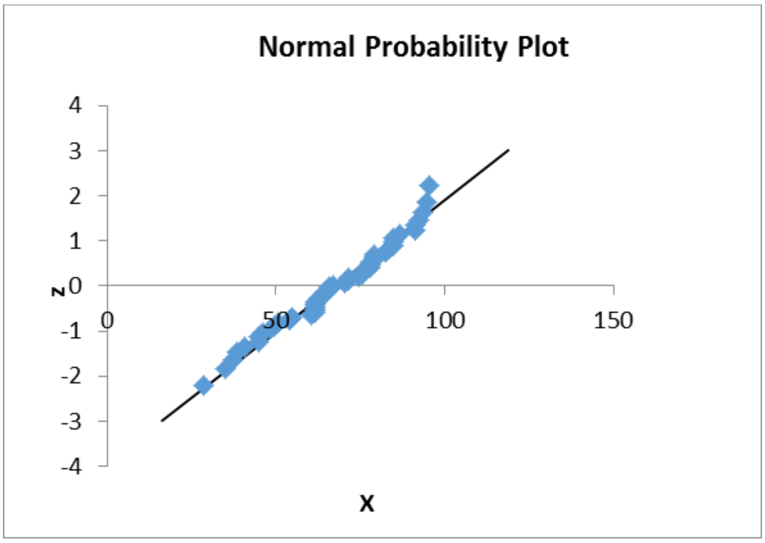
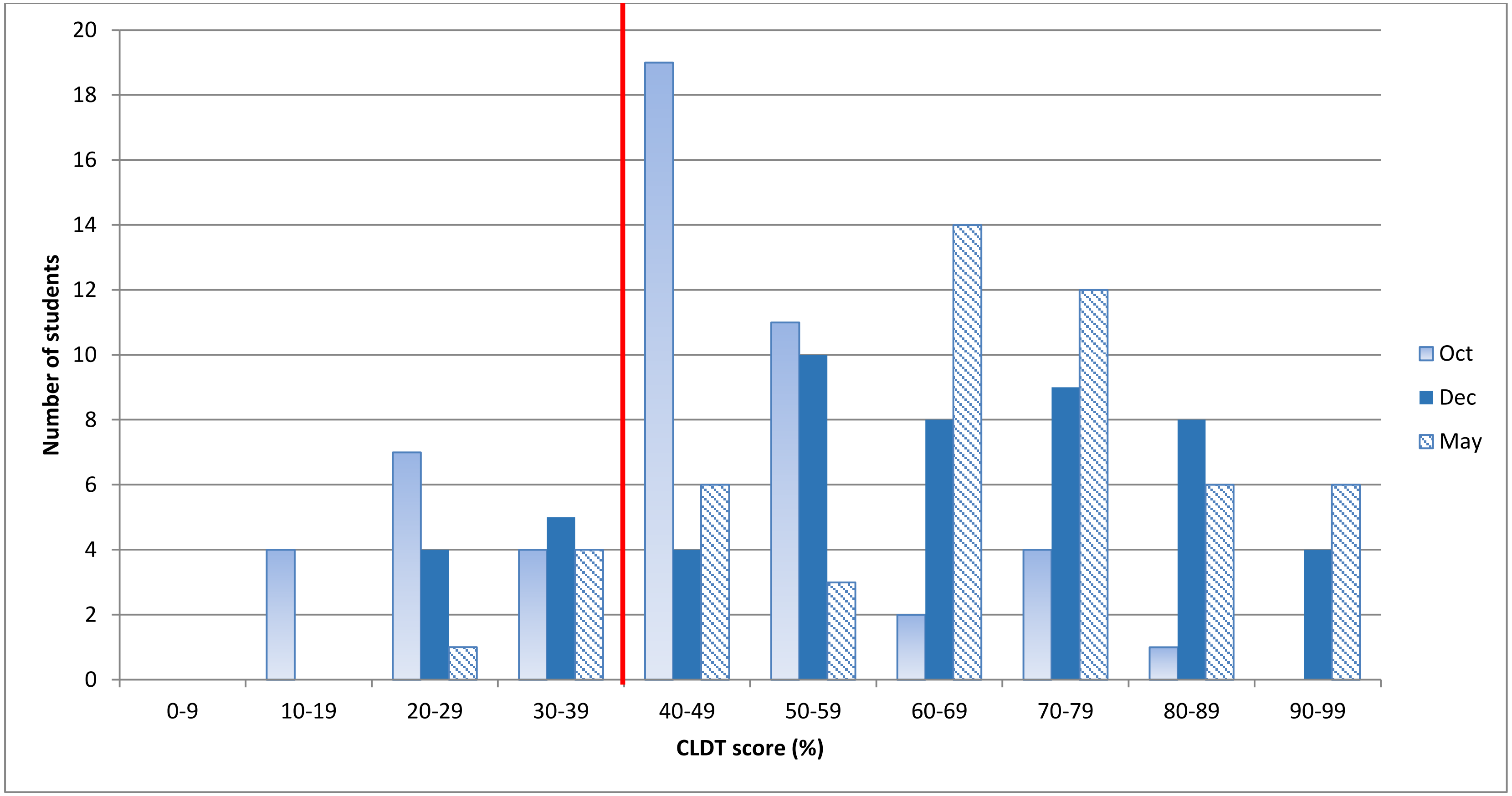


Figure 5.8 May CLDT data normal probability plot

Table 5.8 indicates 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). Less progression from December to May (mean = 67.5, sd = 17.1) and the difference is statistically significant (t = 1.21, p>0.1). This may reflect the Year 0 teaching sequence (Chapter 3, Section 3.3, p. 85) where CLDT topics 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 in Year 0.



Note: Red line indicates the 40% threshold (n = 52)

Figure 5.9 Distribution of AY23 CLDT scores for October, December and May

Table 5.9 shows the three mean scores for the Red and Green sub-groups. The Red sub-group mean score increased from 24.3 (s.d. = 10.1) in October to 42.9 (s.d. = 13.5) in December and to 52.7 (s.d. = 14.1) in May. The Red sub-group showed a substantial improvement from October to December that continued but was reduced in May. The Red sub-group May mean score is similar to the initial mean score for the Green sub-group in October of 52.3 (s.d. = 11.7). The Green sub-group mean score increased to 71.5 (s.d. = 7.5) in December and then to 73.5 (s.d. = 14.6) in May. The mean scores for the two sub-groups were statistically significantly different across the three test dates (Table 5.9). Therefore, at no stage did the Red sub-group catch up with the Green sub-group.

CLDT date	n	mean (%)	standard deviation
October	52	44.2	16.6
December	52	63.3	19.0
May	52	67.5	17.1

Table 5.7 Summary statistics for AY23 CLDT scores

Assessment dates	Mean difference	t	P
October/December	19.1	5.44	<0.001
October/May	4.2	7.06	<0.001
December/May	23.2	1.21	>0.1

t = two tailed t-test p = probability
Grey shading indicates data that are statistically significant.

Table 5.8 Statistical data for CLDT results for AY23

	Red sub-group (n=15)		Green sub-group (n=37)			
CLDT date	Mean	sd	Mean	sd	t	p
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 5.9 CLDT Statistical data for the Red and Green sub-groups

Table 5.10 shows effect sizes for the two sub-groups across the three test dates. The Red sub-group showed a large effect size from October to May (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).

	Cohen's d	
Test interval	Red sub-group	Green sub-group
October – December	1.62	1.52
December – May	0.67	0.15
October – May	2.4	1.65

Table 5.10 Effect size (Cohen's d) for the CLDT results across Year 0 for the Red and Green sub-groups

5.5.1 Analysis of CLDT language component scores across Year 0 by sub-group

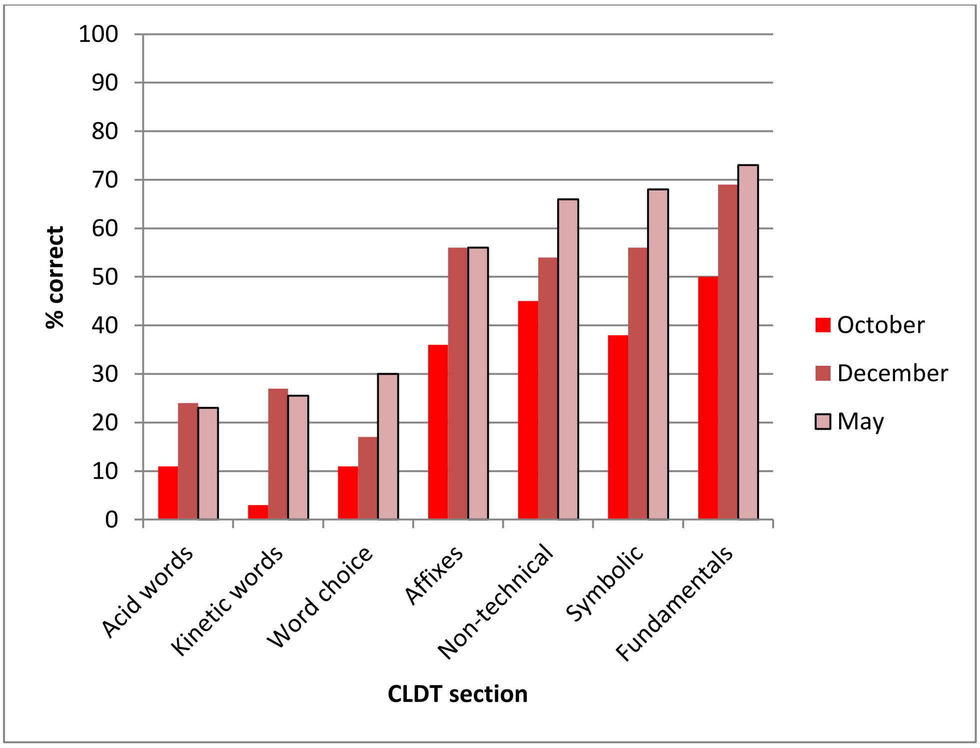
This section analyses CLDT section scores across Year 0 by sub-group. Table 5.11 shows mean May CLDT section scores by sub-group. Figures 5.10 and 5.11 show the change in mean scores by section during Year 0 for the Red and Green sub-groups. Six CLDT sections, *Acid words, Affixes, Fundamentals, Non-technical, Symbolic* and *Word choice* were statistically significantly different in May. Only one section, *Kinetic words*, was not (Table 5.11).

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. This represents weak understanding of these areas of chemical language. These sections are all lexical based and indicate continued weaknesses in knowledge of chemical related vocabulary. Despite experiencing the relevant vocabulary during the year, many students remain unfamiliar with the words at the end of Year 0. From January to May, the Red sub-group shows an increase from 17% to 30% for the *Word choice* section but *Acid words* and *Kinetic words* show 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.

Section	Green sub-group (n=37)		Red sub-group (n=15)		t	p
	Mean score (%)	s.d.	Mean score (%)	s.d.		
Acid words	59	28.1	23	17.2	3.90	<0.001
Affixes	84	20.4	56	27.3	3.49	<0.05
Fundamentals	98	17.4	73	38.8	2.21	<0.05
Non-technical	95	12.1	66	24.6	2.55	<0.05
Word choice	59	19.5	30	17.6	2.61	<0.05
Symbolic	94	18.2	68	27.0	2.31	<0.05
Kinetic words	44	18.4	26	16.9	1.90	>0.05

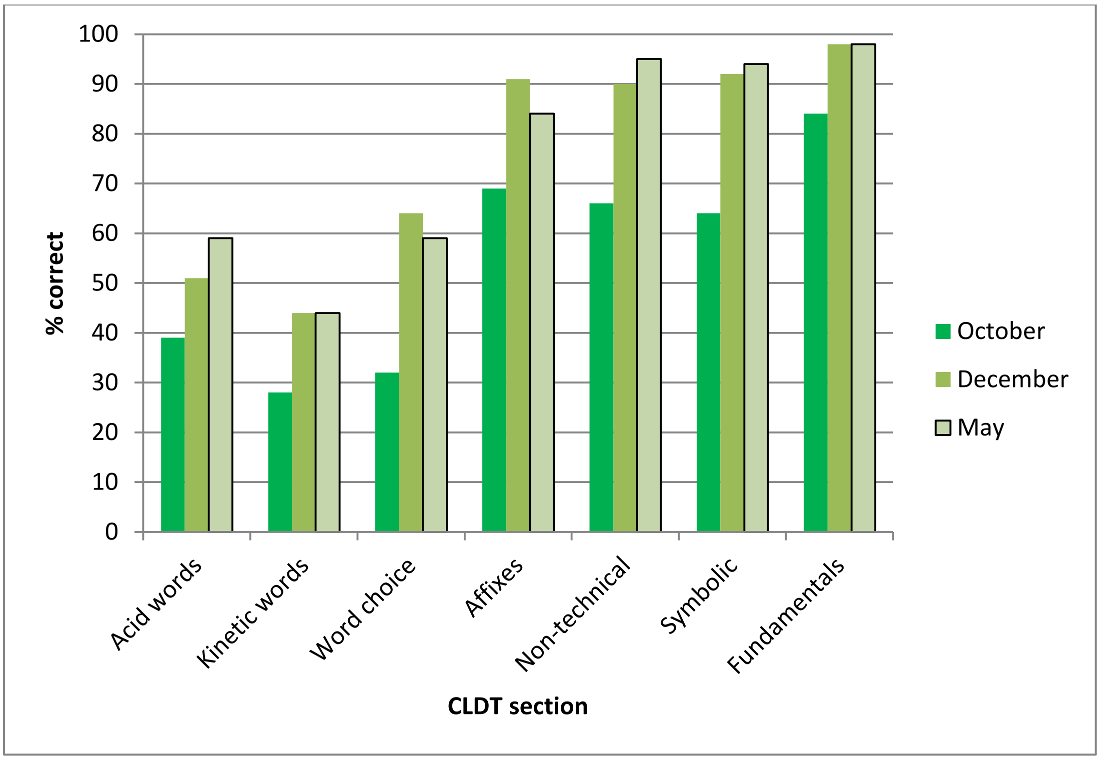
s.d. = standard deviation t= Two tailed t-test p= probability
Grey shading indicates statistically significantly different data.

Table 5.11 Statistical data of May CLDT results for Green and Red sub-groups



n=52

Figure 5.10 Red sub-group CLDT section scores during Year 0



n=52

Figure 5.11 Green sub-group CLDT section scores during Year 0

Figures 5.12 and 5.13 show the proportions of students giving correct responses to each of the *Word choice* questions for Red and Green sub-groups during Year 0. The data indicates continued problematic knowledge of these scientific words for AY23 at the end of Year 0. 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 (Chapter 3, Table 3.2, p. 89). *Dissociate* is encountered in weeks six and nineteen and is a key word for the *Weak* teaching activity in week 9 (Chapter 3, Section 3.3.10., p, 97). However, over 40% of AY23 did not use the word correctly in the May CLDT. *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 (Cassels and Johnstone, 1985) have particularly focused on the challenges of non-technical words and words with dual meaning but these results suggest that understanding of these words can be limited for some students at the end of Year 0.

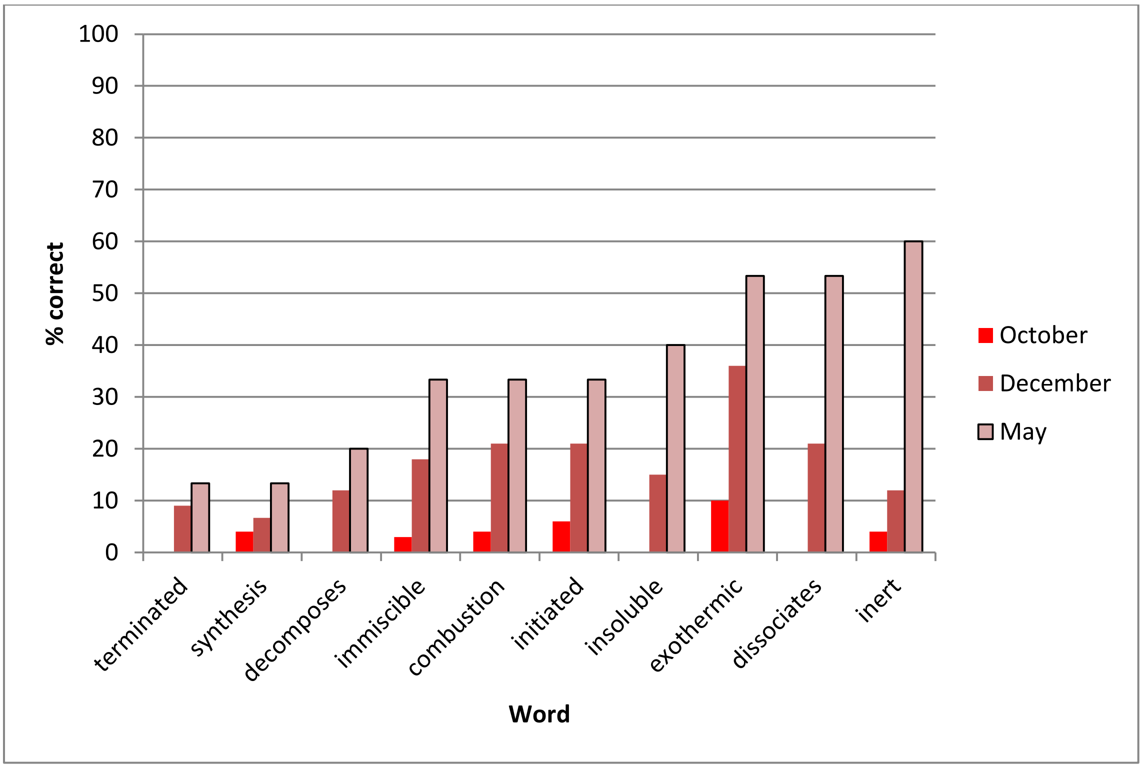


Figure 5.12 Red sub-group percentage correct responses to the CLDT *Word choice* section during Year 0

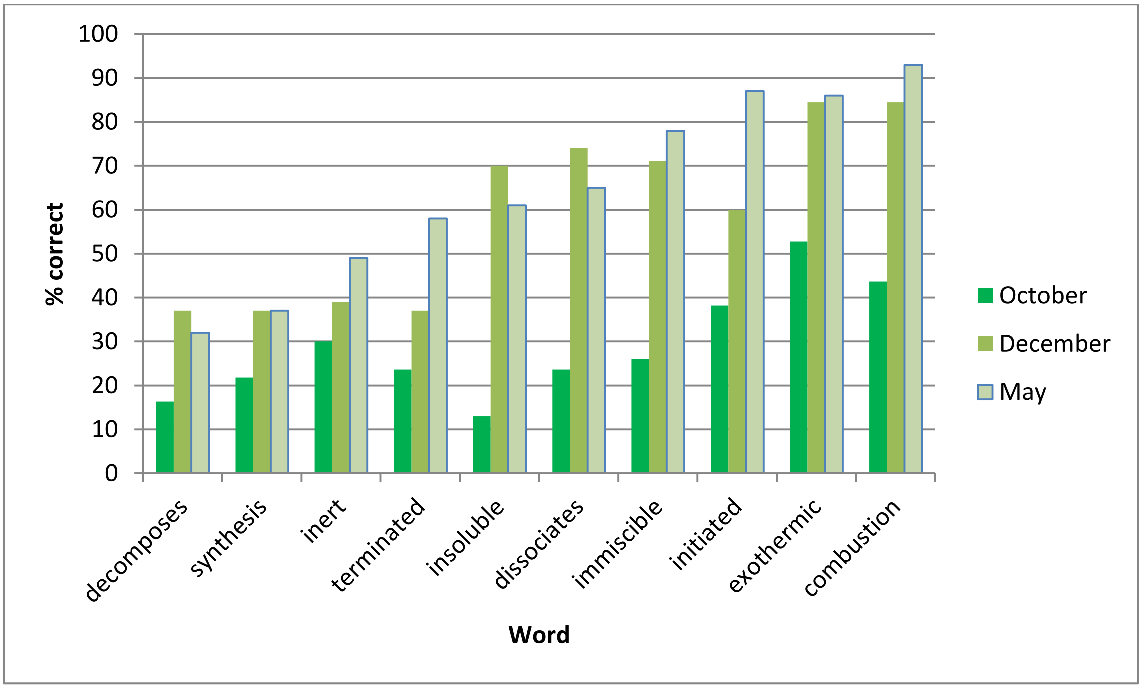


Figure 5.13 Green sub-group percentage correct responses to the CLDT *Word choice* section during Year 0

Word	Correct score (%)		χ^2	p
	Green sub-group (n=37)	Red sub-group (n=15)		
combustion	93	33	21.3	<0.001
initiated	87	33	14.8	<0.001
immiscible	78	33	10.9	<0.001
terminated	58	13	9.5	0.005>p>0.001
exothermic	86	53	7.8	0.05>p>0.01
synthesis	37	13	3.7	>0.05
insoluble	61	40	2.5	>0.05
decomposes	32	20	0.6	>0.1
dissociates	65	53	0.53	>0.1
inert	43	60	0.3	>0.5

χ^2 = Chi squared p = probability
Grey rows highlight words with statistically significant scores.

Table 5.12 Statistical data of the May CLDT *Word choice* section for Green and Red sub-groups

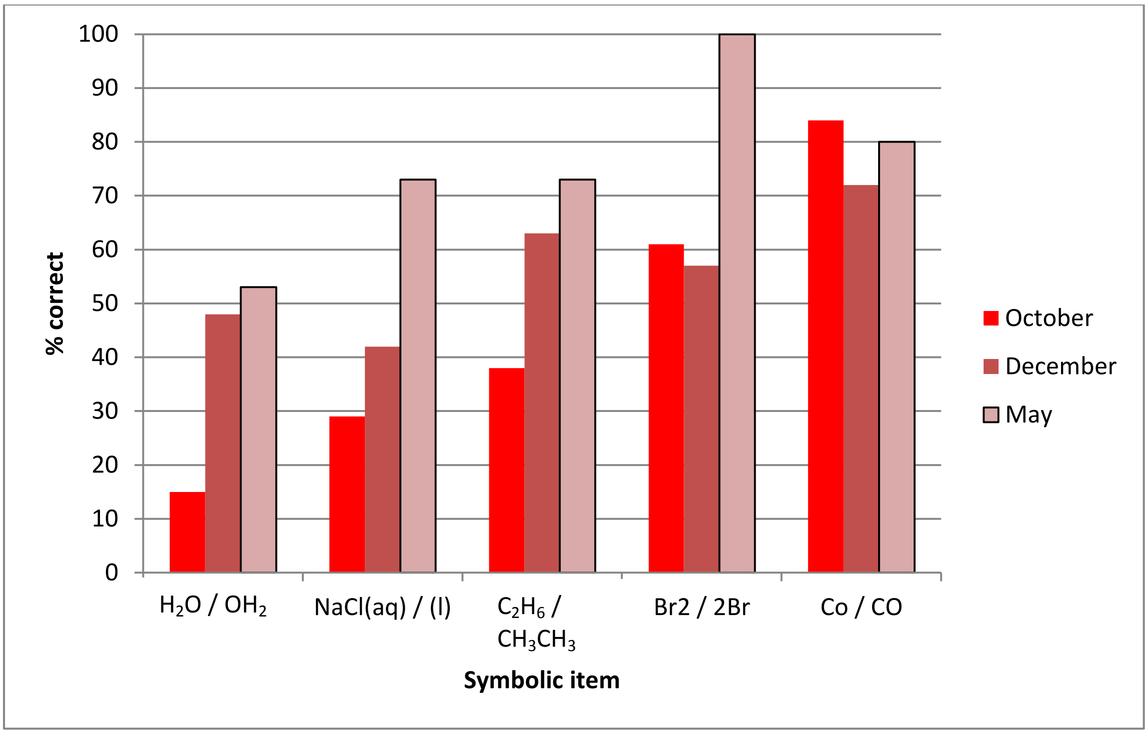
The *Affixes, Non-technical, Symbolic* and *Fundamentals* sections were the highest scoring sections in October and achieved the highest scores in May. The Red sub-group scored over 55% correct in these sections and the Green sub-group scored over 75% correct. There is a general pattern across the different sections showing an initial increase from October to December followed by a plateau in May. This suggests limited progress was made in term two and difficult aspects apparent in December remained so in May. Understanding of affixes was emphasised throughout Year 0 and was the focus of the teaching activity on week 2 (Chapter 3, Section 3.3.2, p. 91). 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 test. The Red sub-group showed improvement in the *Fundamentals* section from October to December and smaller increase increase in May. This suggests that students with limited understanding of these terms in December continued to have difficulty in May.

The *Symbolic* section (Chapter 4, Section 4.8.3, p. 111) generated one of the highest scores for the Red sub-group in October, and the score improved to 68% by May. This may reflect symbolic language usage consistently throughout the year in relation to most chemistry topics. Frequent exposure resulted in improved understanding. The *H_2O/OH_2* and *NaCl(aq)/(l)* items posed the greatest difficulty in October but there was improvement during Year 0 (Figure 5.14 and 5.15). 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 (Table 5.13). This suggests that some Red sub-group students continue to find interpreting chemical formulae problematic at the end of Year 0. Difficulties in understanding formula subscripts have been reported by De Jong and Taber (2014).

Symbolic item	Correct score (%)		χ^2	p
	Green sub-group (n=37)	Red sub-group (n=15)		
H_2O/OH_2	93	53	10.4	$0.005>p>0.001$
Co/CO	100	80	7.9	$0.01>p>0.005$
C_2H_6/CH_3CH_3	98	73	7.2	$0.01>p>0.005$
NaCl(aq)/(l)	96	73	7.1	$0.01>p>0.005$
$Br_2/2Br$	100	100	-	-

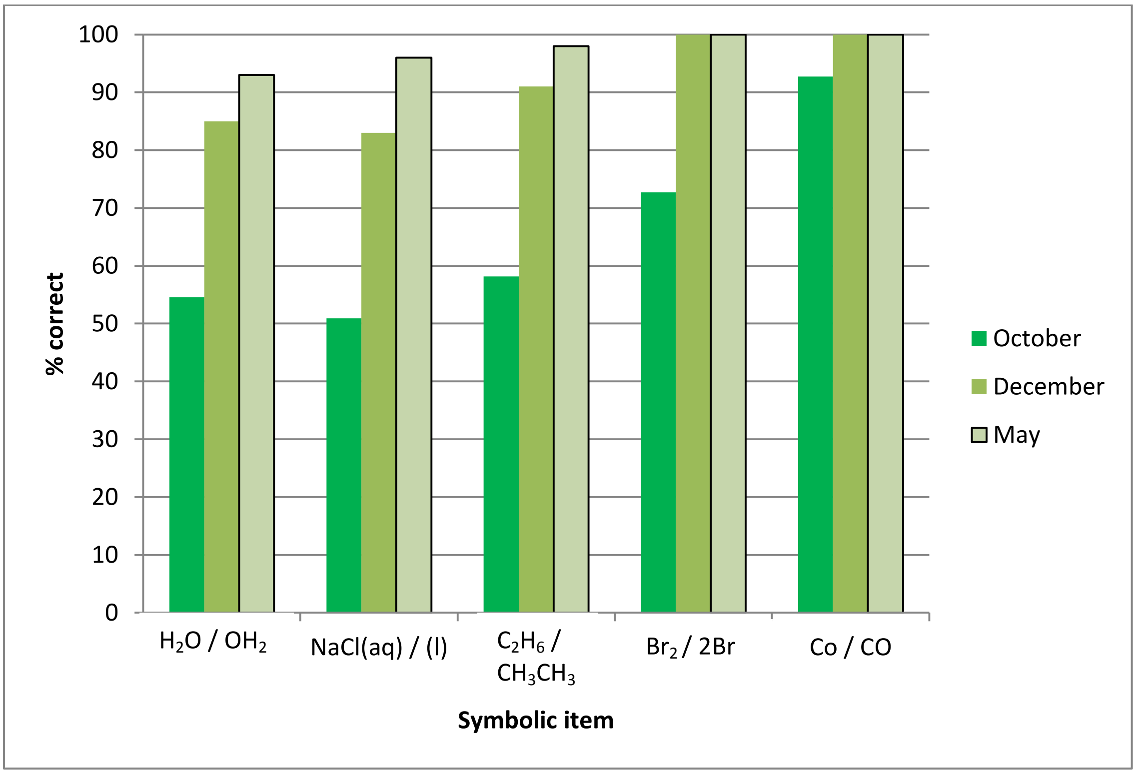
χ^2 = Chi squared p = probability
Grey rows highlight items with statistically significant scores.

Table 5.13 Statistical data for the May CLDT *Symbolic* section results for Green and Red sub-groups



n=15

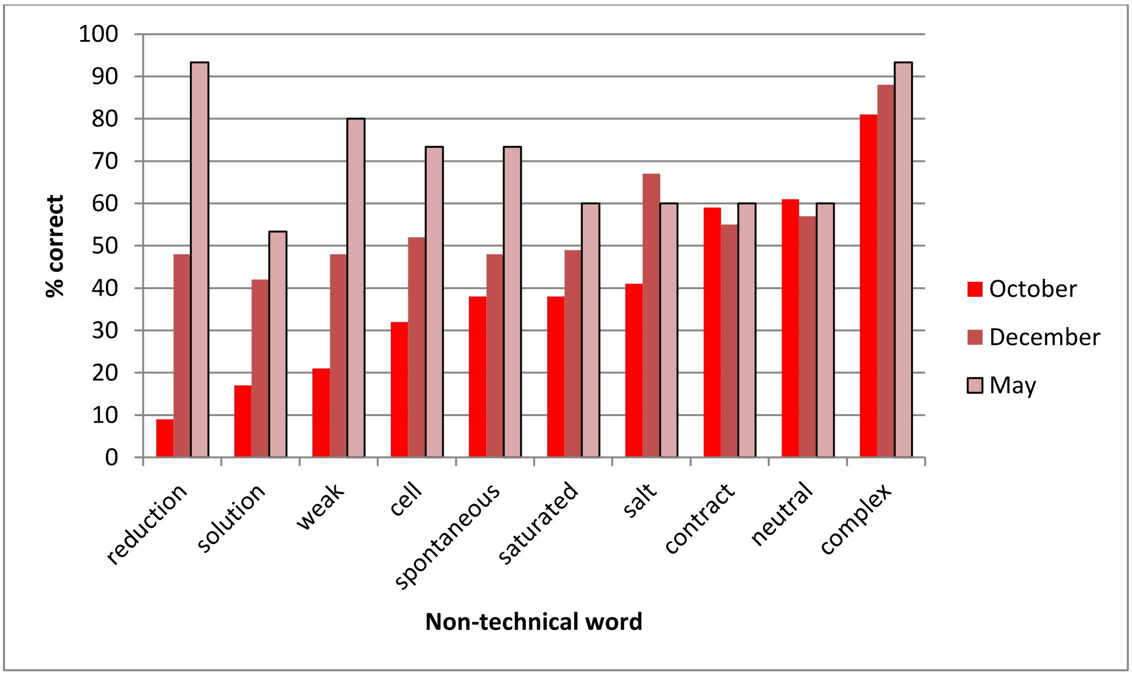
Figure 5.14 Red sub-group percentage correct responses to the CLDT *Symbolic* section during Year 0



n=37

Figure 5.15 Green sub-group percentage correct responses to the CLDT *Symbolic* section during Year 0

In the *Non-technical* section (Chapter 4, Section 4.8.3, p. 111), the results suggest three different types of words can be identified for the Red sub-group (Figure 5.16).

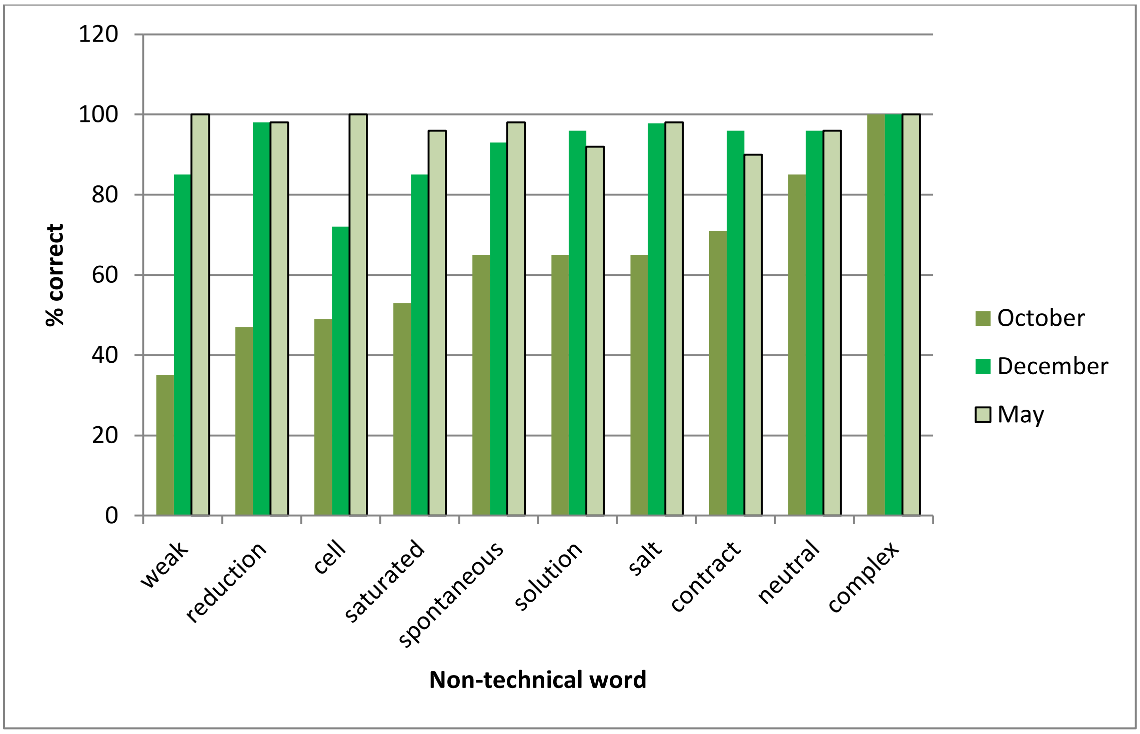


n=15

Figure 5.16 Red sub-group percentage correct responses to the CLDT *Non-technical* word section during Year 0

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, some words students understood poorly in October with scores between 5% and 40% correct showed improved understanding in May to between 50% and 95% correct. These words were *Solution, Cell,* S*pontaneous, Reduction and Weak.* This suggests the teaching activities had developed students' understandings of these words. The meanings of *Solution*, *Cell*, *Reduction* and *Weak* were taught explicitly during Year 0 and *Weak* was the focused on in week 19. 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. Students did not understand the meaning of these words in October or May. The meaning of *Salt* and *Saturated* was taught explicitly in weeks 6 and 15 respectively (Chapter 3, Table 3.1, p. 87). The meaning of

Contract was not taught explicitly during Year 0. The CLDT question for *Contract* (Appendix 16) asks students to distinguish between the meaning of "*becoming narrower*" and "*becoming smaller*" in the context of the question specifically referring to capillaries. Students may not have distinguished between these alternative responses. *Neutral* was more frequently used in the context of *pH* than a *neutral atom*. This could account for students not understanding the meaning of a *neutral atom* in May. Figure 5.17 shows the Green sub-group reported similar trends to the Red sub-group.



n=37

Figure 5.17 Green sub-group percentage correct responses to the CLDT *Non-technical* word section during Year 0

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 5.14 shows the Red sub-group continued to score significantly less for all non-technical words in May with scores for *Reduction* and *Complex* not being significantly different. Lemke (1990) states the importance for teaching explicitly and modelling the meanings of such words. These results indicate that even when this occurs, the meanings of some words (such as *Salt* and *Saturated*) remain poorly understood by some students.

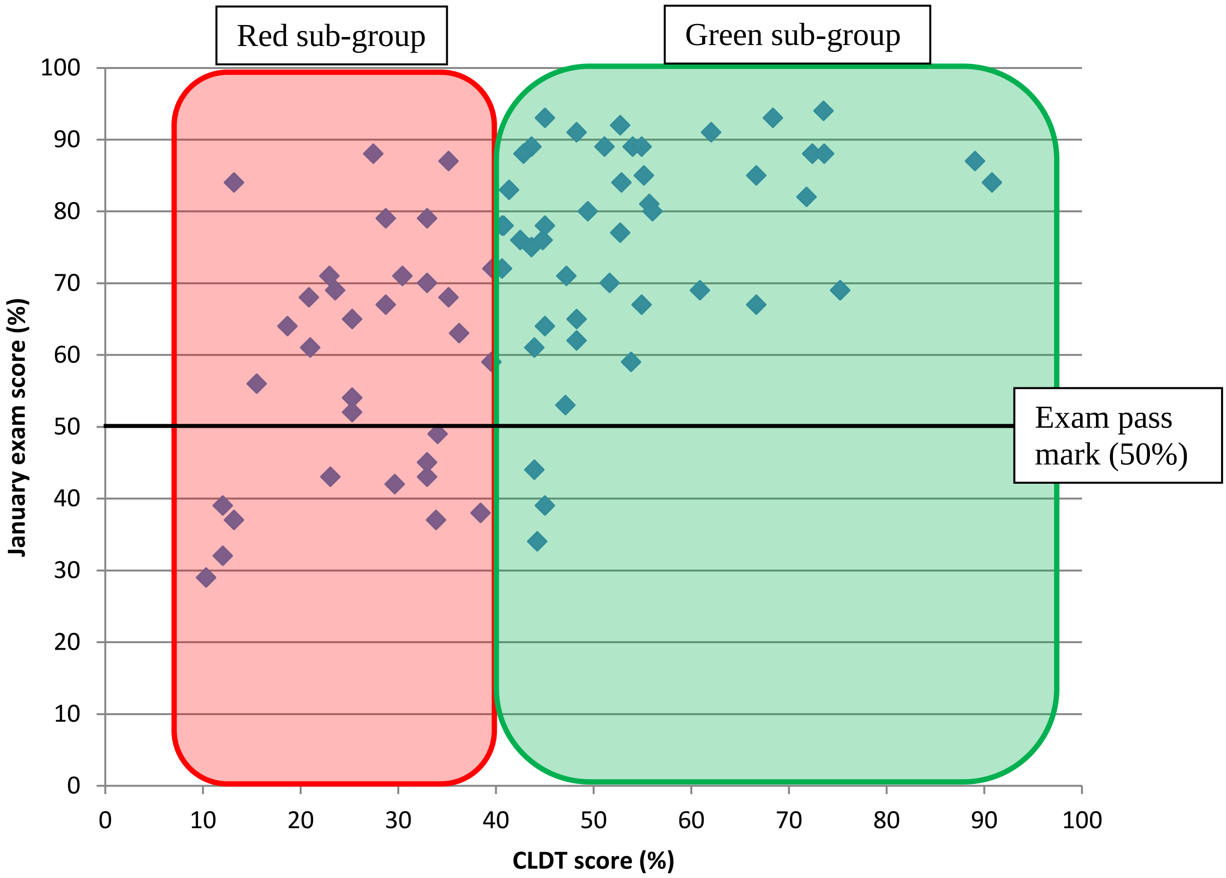
Non-technical word	Correct score (%) Green sub-group (n=37)	Red sub-group (n=15)	χ^2	p
Salt	98	60	12.7	<0.001
Saturated	96	60	12.7	<0.001
Cell	100	73	11.7	<0.001
Solution	92	53	11.6	<0.001
Neutral	96	60	11.4	<0.001
Weak	100	80	7.9	$0.01>p>0.005$
Spontaneous	98	73	7.3	$0.005>p>0.001$
Contract	90	60	5.2	$0.05>p>0.01$
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 5.14 Statistical data of the May CLDT Non-technical section for Green and Red sub-groups

5.6 Comparison of CLDT and Year 0 chemistry exam scores

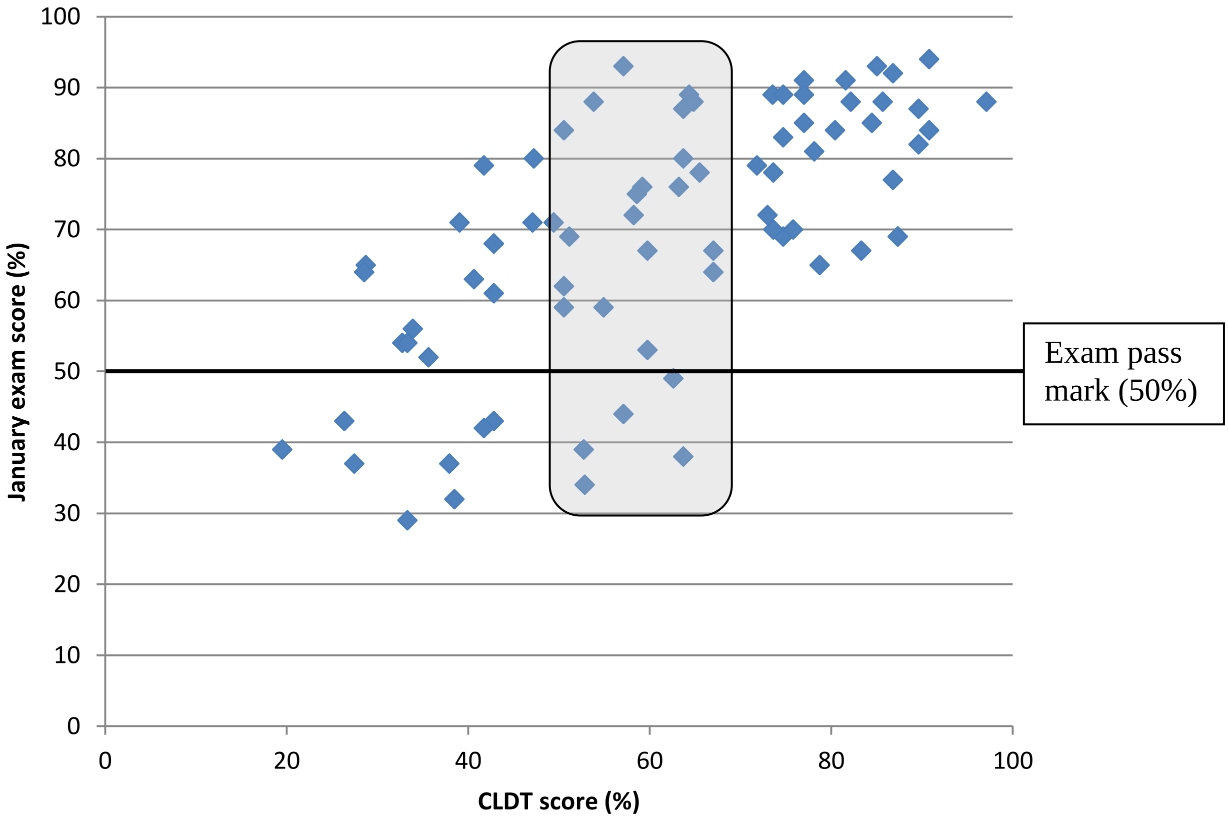
This section investigates student CLDT and chemistry examination marks to answer Research Question 2. The chemistry examinations in January and May are explained in Chapter 3, Section 3.2, p. 85) and are available in Appendix 22. Figure 5.18 plots individual October CLDT scores against January exam scores. Moderate correlation (r=0.55) between the October CLDT score and the January exam result is observed. This suggests that chemical language knowledge is correlated with exam performance. In the Green sub-group (shaded green section), three students that scored over 40% in the October CLDT scored below 50% in the January exam but every student who scored over 47% in the October CLDT passed the January exam scoring greater than 50%. Within the Red sub-group, who scored below 40% in the October CLDT, eleven students (37% of Red sub-group students) failed the January exam. A low CLDT score indicates that an individual was more likely to fail the January exam. However, a large range of exam scores from 28 to 88% within the Red sub-group indicates that some students with low CLDT scores in October made substantial progress during the first term of Year 0.



n=81 r = 0.55

Figure 5.18 Scatter plot showing AY23 January exam scores against October CLDT scores

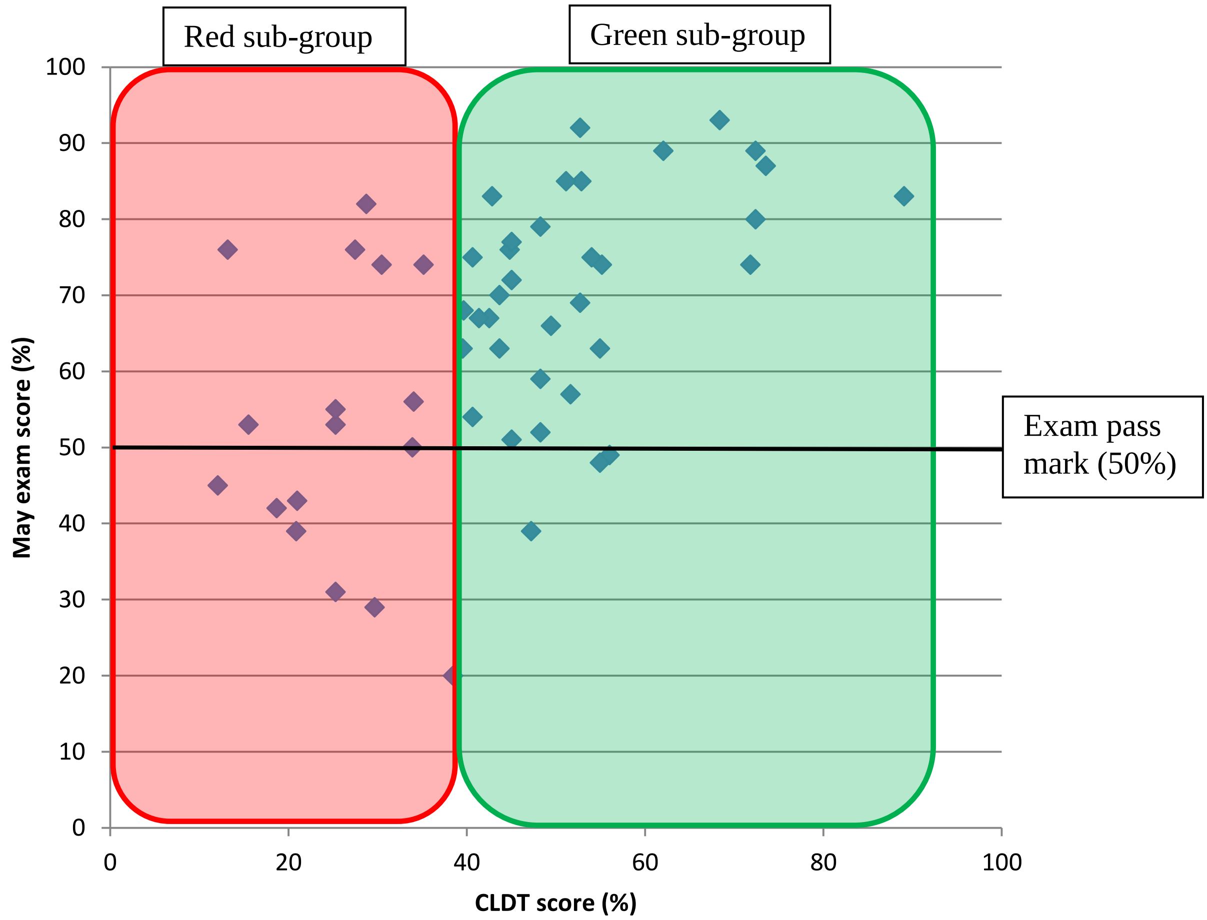
Figure 5.19 plots the January exam score against the December CLDT score. The correlation coefficient (r) is 0.67 between the December CLDT and January exam scores. This higher correlation than for October CLDT score is to be expected as the December CLDT occurred closer to the time of the January exam. CLDT scores in the range from 45% to 65% (Figure 5.19 - grey box) show a large range of exam scores from 33% to 93%. This shows five students with good chemical language comprehension did not perform well in the exam. This may be because they did not prepare for the exam thoroughly or other factors such as personal circumstances may have affected their performance.



n = 78   r = 0.67

Figure 5.19 Scatter plot showing January exam scores against December CLDT scores

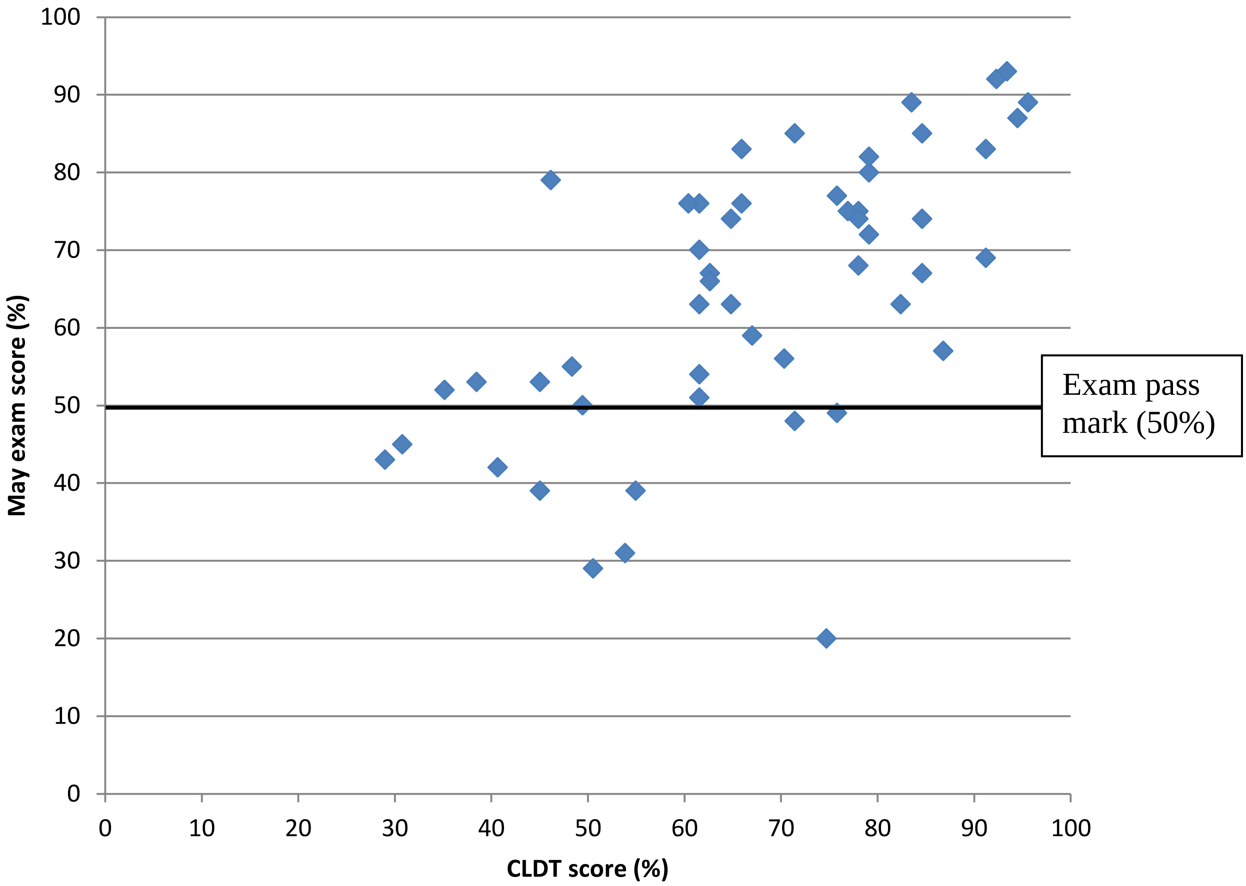
Figure 5.20 shows May chemistry exam score against October CLDT score. The correlation coefficient (r) is 0.53 indicating that the October CLDT score correlates with the final May exam score. Seven out of fifteen (44%) Red sub-group students failed the May exam with scores of less than 50%. Three out 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 CLDT was more likely to fail the final examination than those scoring highly in the October CLDT. 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 over Year 0. 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. These factors are considered in Chapter 6.



n = 52 r = 0.53

Figure 5.20 Scatter plot showing May exam scores against October CLDT scores

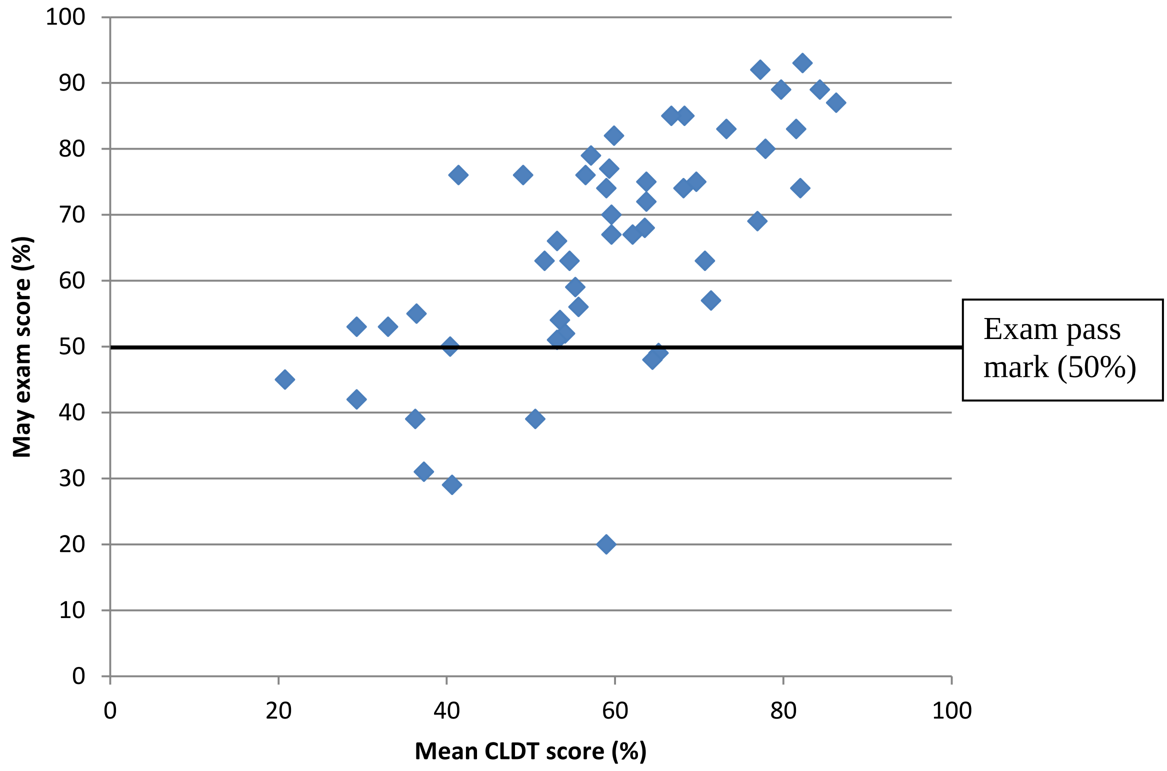
Figure 5.21 shows May exam scores plotted against May CLDT scores. A strong correlation is observed between May exam and May CLDT scores (r = 0.63). This indicates that students who continued to have poor chemical language comprehension in May also, generally, performed poorly in the May chemistry exam.



n = 51   r = 0.53

Figure 5.21 Scatter plot showing May exam scores against May CLDT scores

Figure 5.22 shows the mean CLDT scores plotted against the May chemistry exam score for those students that completed all three CLDTs and the May exam. The decrease in students studying chemistry across Year 0 is explained in Chapter 3 (Section 3.2 p. 85). A strong correlation (r = 0.67) is observed between these two results. This suggests that chemical language comprehension ability across Year 0 correlates with final chemistry exam outcome.



n = 50 r = 0.67

Figure 5.22 Scatter plot showing May exam score against mean CLDT score

5.7 Final outcomes for Red sub-group students

CLDT results in Section 5.5.1 demonstrate that Red sub-group students continued to have difficulties understanding chemical language at the end of Year 0. Section 5.6 shows that individuals who scored less than 40% in the October CLDT were more likely to fail the January and May Chemistry exams than those scoring greater than 40%. This section tracks individual red sub-group results in detail.

Table 5.15 shows that 61% of Red sub-group students were home students with English as their first language, and that the same numbers of home and international students failed. Therefore, chemical language comprehension presents a challenge for native English speakers and international students alike. Individual outcomes for the 2013 red sub-group are reported in Table 5.16. The outcomes were poor with only four out of the fourteen students (29%) successfully passing undergraduate Year 1. Two students passed Year 0 but failed Year 1; five students failed to pass Year 0 and three students withdrew for personal reasons.

Outcome	Home	International
Passed	10 (53%)	5 (42%)
Failed	6 (32%)	6 (50%)
Withdrew	3 (15%)	1 (8%)
Total	19	12

Table 5.15 Year 0 final outcomes for home and international Red sub-group students

Degree programme	October CLDT (%)	December CLDT (%)	January exam result (%)	May CLDT (%)	Year 0 outcome*	Year 1 classification
Successfully completed Year 1						
Chemistry	29	72	79	79	pass (82%)	2:1
Computer science	29	60	67	n/a	pass	2:2
Earth sciences	30	47	71	n/a	pass	2:1
Earth sciences	25	29	65	n/a	pass	2:2
Successfully completed Year 0 but failed Year 1						
Biomedical science	16	34	56	38	pass (53%)	fail
Biomedical science	34	38	37	49	pass (50%)	fail
Failed Year 0						
Biological science	25	33	54	54	fail (31%)	
Computer science	24	51	69	n/a	fail	
Physics	10	33	29	n/a	fail	
Chemistry	12	20	39	31	fail (45%)	
Medicine	25	36	52	48	fail (47%)	
Withdrew during Year 0						
Biological science	25	33	54	withdrew		
Earth sciences	12	39	32	withdrew		
Biological science	37	43	withdrew			

* Percentage scores indicate May Chemistry exam results where available.
n/a = not applicable (CLDT not taken)

Table 5.16 Year 0 final outcomes for home and international Red sub-group students

Outcomes for AY3 Red sub-group students are reported in Table 5.17. Ten out of the seventeen students (71%) passed Year 0, one student withdrew and the remaining six failed Year 0.

Degree programme	October CLDT (%)	December CLDT (%)	January exam result (%)	May CLDT (%)	Year 0 outcome*
Passed Year 0					
Engineering	33	74	70	n/a	pass
Pharmacy	34	63	49	70	pass (56%)
Engineering	35	43	68	n/a	pass
Computer science	23	26	43	n/a	pass
Computer science	33	43	43	n/a	pass
Engineering	36	41	63	n/a	pass
Biological science	27	54	88	66	pass (76%)
Medicine	13	51	84	60	pass (76%)
Biological sciences	35	64	87	78	pass (74%)
Physics	33	42	79	n/a	pass
Failed Year 0					
Medicine	38	64	38	75	fail (20%)
Pharmacy	19	29	64	41	fail (42%)
Pharmacy	30	42	42	51	fail (29%)
Pharmacy	21	43	68	45	fail (39%)
Biological science	13	27	37	n/a	fail (35%)
Biological science	21	n/a	61	29	fail (43%)
Withdrew					
Biological science	33	n/a	45	withdrew	

* Percentage scores indicate May Chemistry exam results where available.
n/a = not applicable (CLDT not taken)

Table 5.17 2014 AY3 Red sub-group cohort: tracking to the end of Year 0

In the combined cohort (AY23), there were six students who scored below 40% in the October and December CLDT and below 50% in the May CLDT. Two of these students passed the May exam but failed Year 1, while the other four students failed Year 0. This indicates that these students failed to respond to the teaching activities and make progress in their chemistry studies. In AY23 six students scored below 40% in October and over 60% in May. One of these students failed Year 0 and five of these were continuing with their studies at the end of this project. This indicates that students who made significant improvements in their chemical language understanding and CLDT score in Year 0 were very likely to be successful. The remaining nineteen AY23 students were potential undergraduates who studied chemistry in term 1 only for who no May CLDT results are available. Of these students, five scored below 40% in the December CLDT. One of these passed Year 1, one passed Year 0, one failed Year 0 and two students withdrew. Nine students scored above 40% in the December CLDT. Two of these students have passed Year 1, five passed Year 0, one failed Year 0 and one student withdrew. Therefore, data indicates that there are two groups of potential undergraduates within the Red sub-group: those students who responded to the teaching activities and improved their CLDT scores; and those students who did not respond to the teaching activities and failed to improve their CLDT scores. Chapter 6 reports individual student interview data to provide insight into why some potential undergraduates responded to the teaching activities, made progress and were successful whilst some did not respond and were less likely to be successful.

5.8 Summary

The baseline October CLDT data identified thirty one potential undergraduates who scored below 40% and demonstrated limited understanding of chemical language at the start of Year 0. CLDT score correlates with chemistry examination score, potential undergraduates in the Red sub-group were less likely to be successful than potential undergraduates in the Green sub-group. The Red sub-group CLDT score increased during Year 0 but remained significantly below the Green sub-group. Red sub-group students who improved their CLDT score during Year 0 were more likely to be successful than those students who did not.

Baseline data from October CLDT results indicate that the word family and word choice sections were most problematic for AY23 students overall. These sections continued to generate the lowest scores at the end of Year 0. Improvements in responses shown by the Red sub-group to individual items was varied within sections of the CLDT test. In the *Non-technical* section for example, understanding of some words increased during Year 0 whereas some understanding of some words did not.

The next section describes the results of the eye tracker study.

5.9 Eye tracker study

The Mangold Vision® Eyetracker system (Chapter 4, Section 4.10 p. 118) was used to investigate student reading of unfamiliar text. The text required comprehension of aspects of chemical language detailed in Section 4.10.1 (Chapter 4, p. 119) Responses from students are discussed in relation to the two sub-groups established from the October CLDT scores.

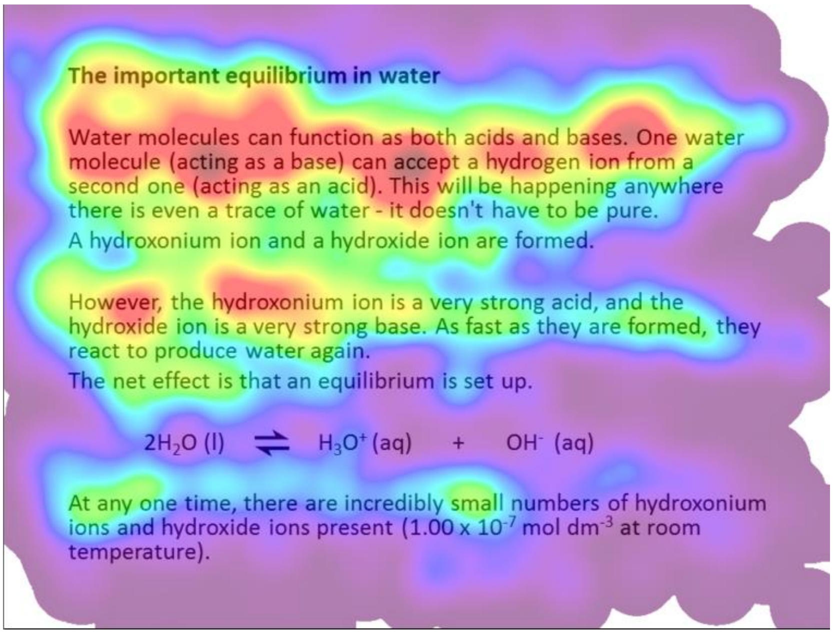
5.9.1 Potential undergraduate eye movement patterns

Section 4.10.1, (Chapter 4, p. 119) discussed the macroscopic, sub-microscopic and symbolic level components of the eye tracker task slides. The chemical language content was also discussed in relation to the Chemical Language Diagnostic Test (CLDT) sections. This section discusses the heat map results for the eye tracker task for Red and Green sub-group students identified in Section 5.3.1, p. 140. The results are considered within the themes of transitioning between macroscopic and sub-microscopic levels, interpreting symbolic language, scientific vocabulary, non-technical vocabulary, unfamiliar phrases, saccades and regressions.

5.9.2 Transitioning between macroscopic and sub-microscopic levels

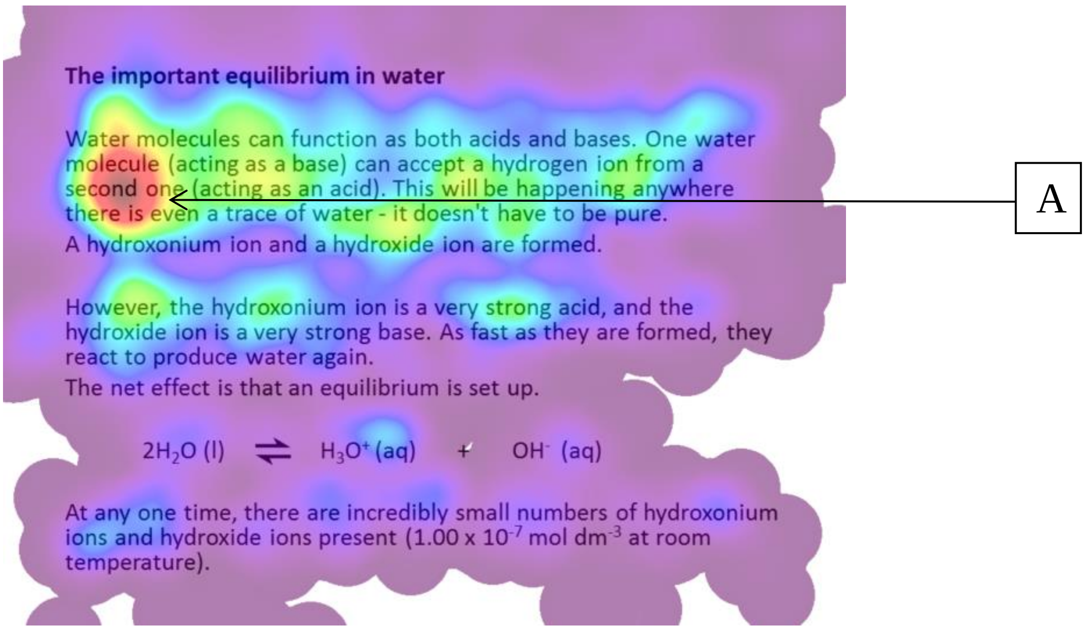
In November, Red sub-group students (n=6) demonstrate widespread and intense focus throughout the first paragraph of "*The important equilibrium in water*" slide (Figure 5.23).

The Green sub-group students (n=14) attention is less widespread and intense with a particular point of focus towards the end of the second sentence on the phrase "second one" (labelled "A", Figure 5.24). Larger sample sizes would be expected to result in greater individual variability (Section 4.10.2, p. 125) and more widespread results. However, in this case, it is the Red sub-group students with the lower sample size that exhibit a more widespread pattern.



n = 6

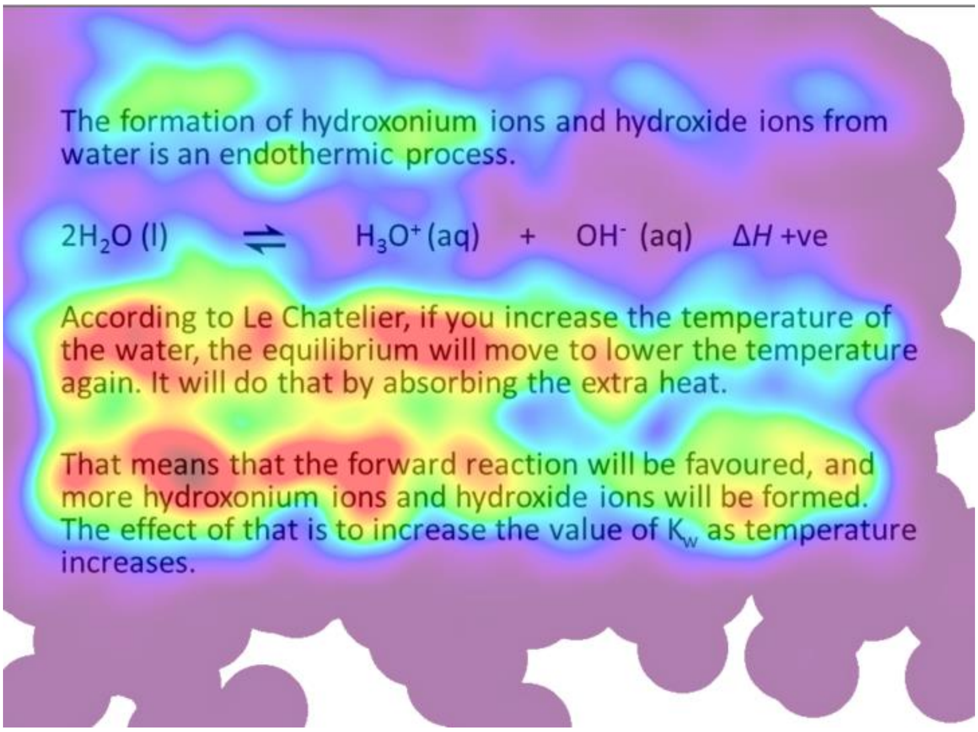
Figure 5.23 November Red sub-group heat map for "*the important equilibrium in water*" slide



n = 14

Figure 5.24 November Green sub-group heat map for "*the important equilibrium in water*" slide

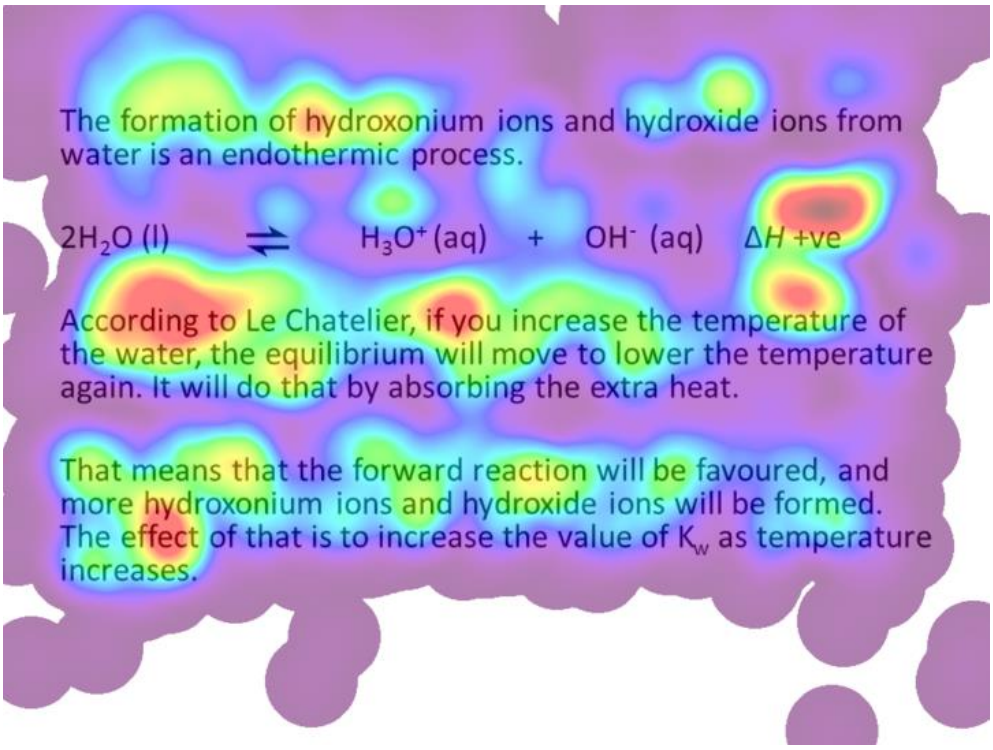
The title and first paragraph require transitions between the macroscopic and sub-microscopic levels and uses a wide array of CLDT relevant vocabulary (Chapter 4, Section 4.10.1 p. 119). The widespread focus and attention by Red sub-group students suggests they had more difficulty reading and comprehending the text than Green sub-group students. This may relate to weaker knowledge of chemical language demonstrated by the October CLDT scores (Chapter 5, Section 5.3.1, p. 140). A similar pattern is observed in the final paragraph of the "*Effect of Temperature*" slide (Figure 5.25).



n = 6

Figure 5.25 November Red sub-group heat map for "*the effect of temperature on the equilibrium in water*" slide

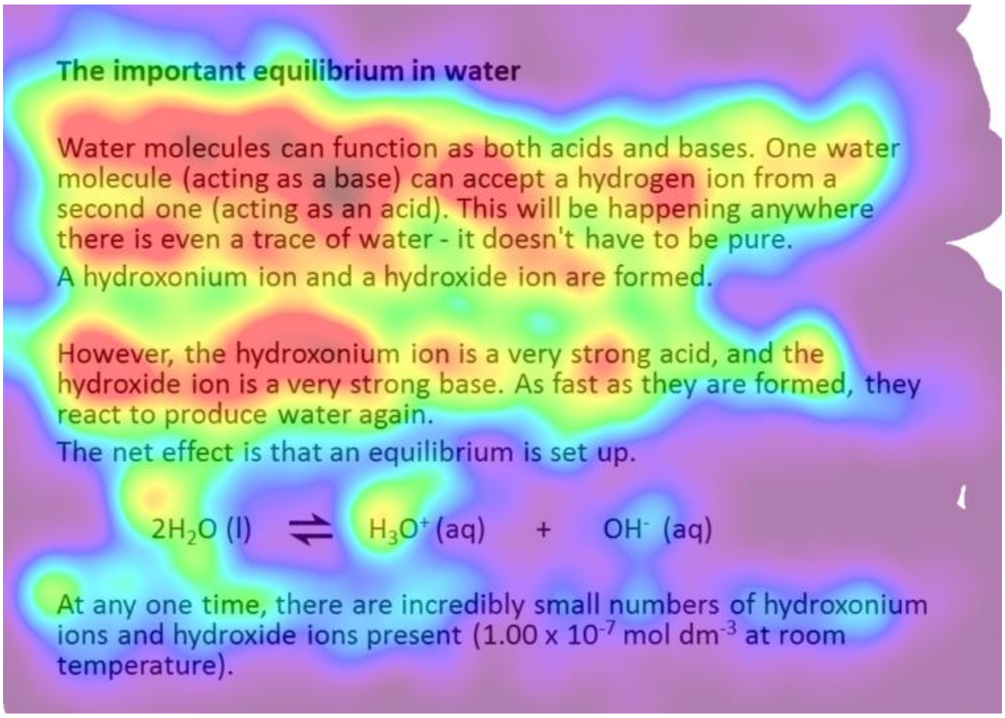
Red sub-group students demonstrate more widespread and intense focus than Green sub-group students (Figure 5.26). This paragraph transitions between the sub-microscopic, symbolic and macroscopic levels and also contains a wide array of CLDT vocabulary (Chapter 4, Section 4.10.1, p. 119). These results suggest that weaker understanding of chemical language makes it difficult to comprehend text that transitions between the macroscopic, sub-microscopic and symbolic levels.



n = 14

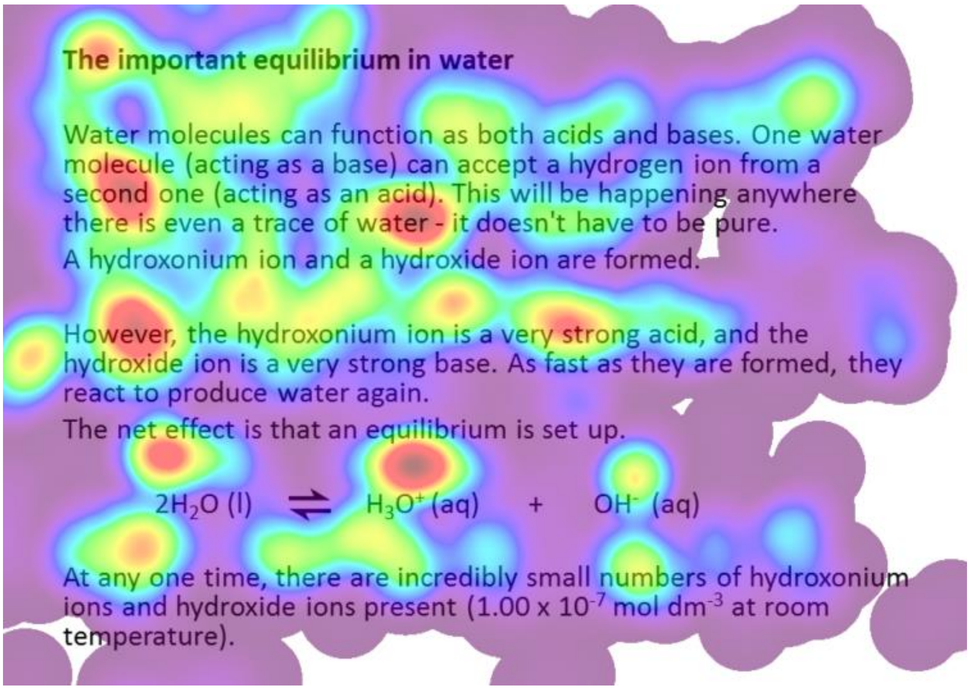
Figure 5.26 November Green sub-group heat map for "*the effect of temperature on the equilibrium in water*" slide

The same observation can be made in the first paragraph of "*The important equilibrium in water*" slide in April. The Red sub-group students show more widespread and intense focus (Figure 5.27) than the Green sub-group students (Figure 5.28).



n = 3

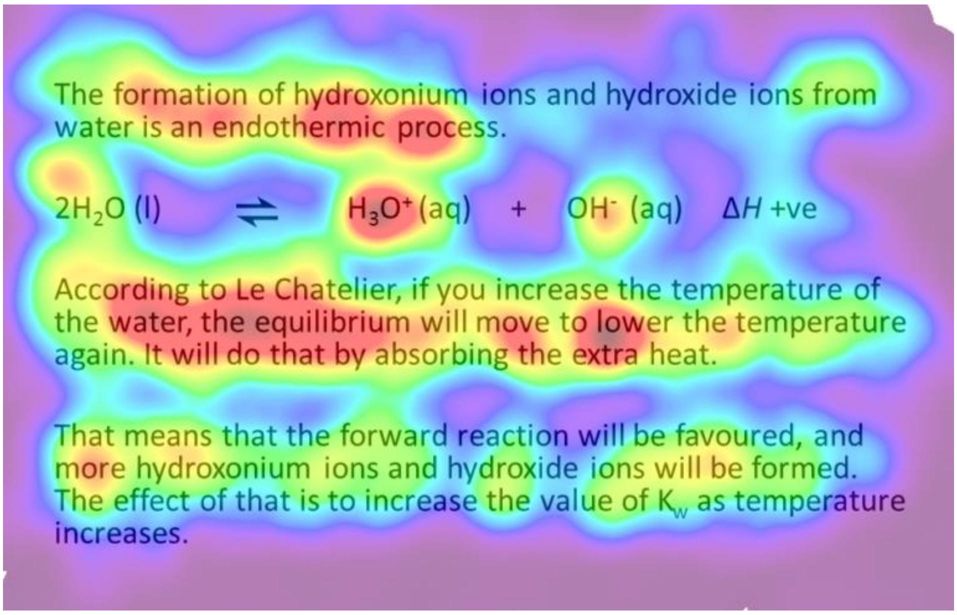
Figure 5.27 April Red sub-group heat map for "*the important equilibrium in water*"



n = 10

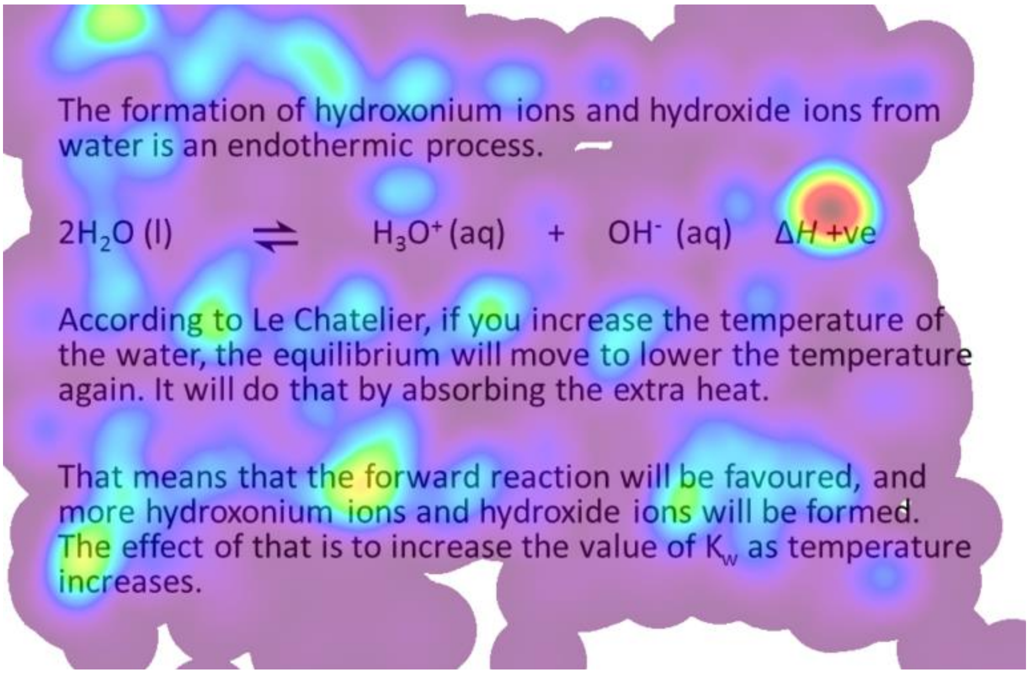
Figure 5.28 April Green sub-group heat map for "*the important equilibrium in water*"

This observation is repeated with the final paragraph of the "*effect of temperature*" slide for Red sub-group students (Figure 5.29) and Green sub-group students (Figure 5.30) in April. Therefore, despite improvements in CLDT scores for Red sub-group students during Year 0, they continue to have more difficulty reading the text than Green sub-group students.



n = 3

Figure 5.29 April Red sub-group heat map for "*the effect of temperature on the equilibrium in water*" slide

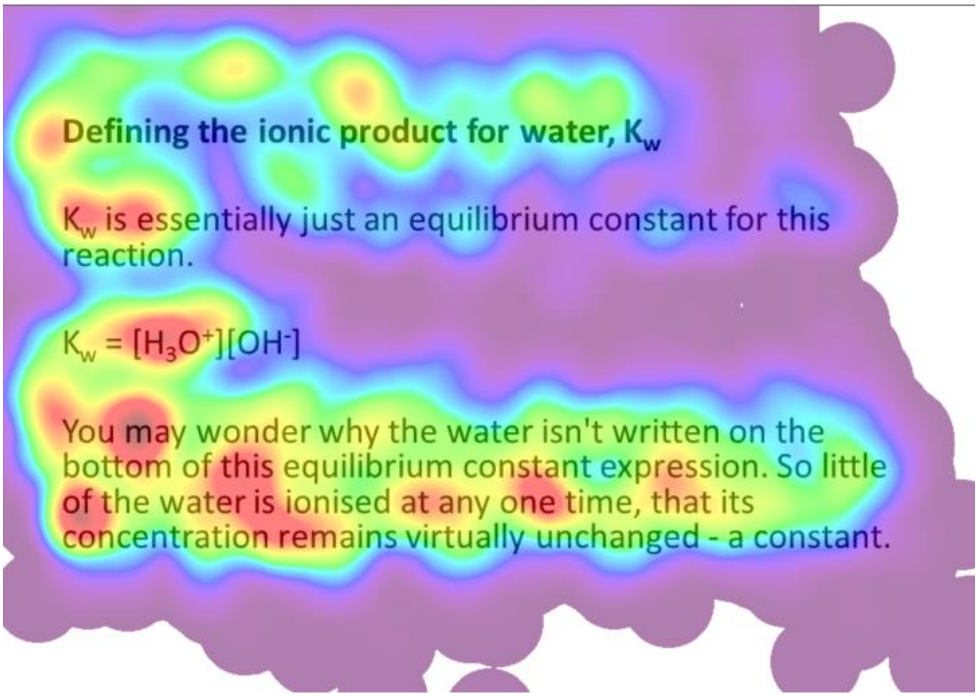


n = 10

Figure 5.30 April Green sub-group heat map for "*the effect of temperature on the equilibrium in water*" slide

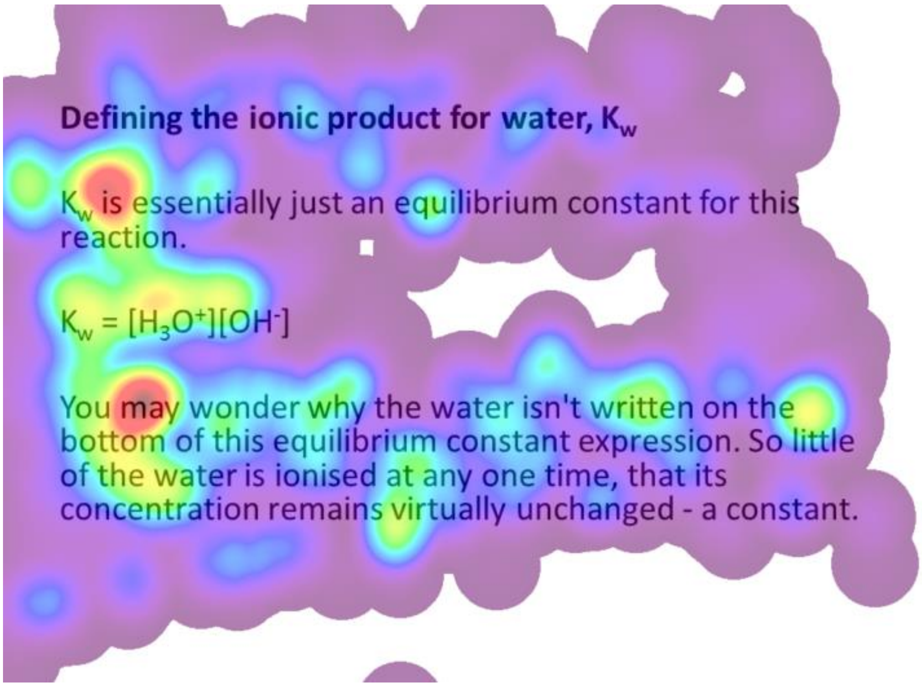
5.9.3 Interpretation of symbolic language

In November, Red sub-group students focus little attention on the equations in "*the important equilibrium in water*" slide (Figure 5.20) and "*the effect of temperature*" slide (Figure 5.25). In April, however, these students demonstrate attention to these equations (Figures 5.27 and 5.29). This is corroborated by low scores in the Symbolic section of the October CLDT (Figure 5.3, p.145) and avoidance of symbolic language in November. Higher scores for this section in the May CLDT (Figure 5.9, p. 155) reflect that students are prepared to engage with the equations in April. Green sub-group students also show a similar pattern with little attention focused on the equations in November (Figure 5.26) but greater attention in April (Figure 5.28), even though this group scored higher in the Symbolic section of the October CLDT. This suggests that all students tended to avoid the equations initially. In the "*important equilibrium of water*" and "*the effect of temperature*" slides, equations reinforce the explanations in the text. In contrast, all students focused on the equilibrium constant expression in November contained in the "*ionic product of water*" slide (Figure 5.31 and 5.32). This may reflect that this expression is central to the explanation of the slide and the expression is not explained in the text.



n = 6

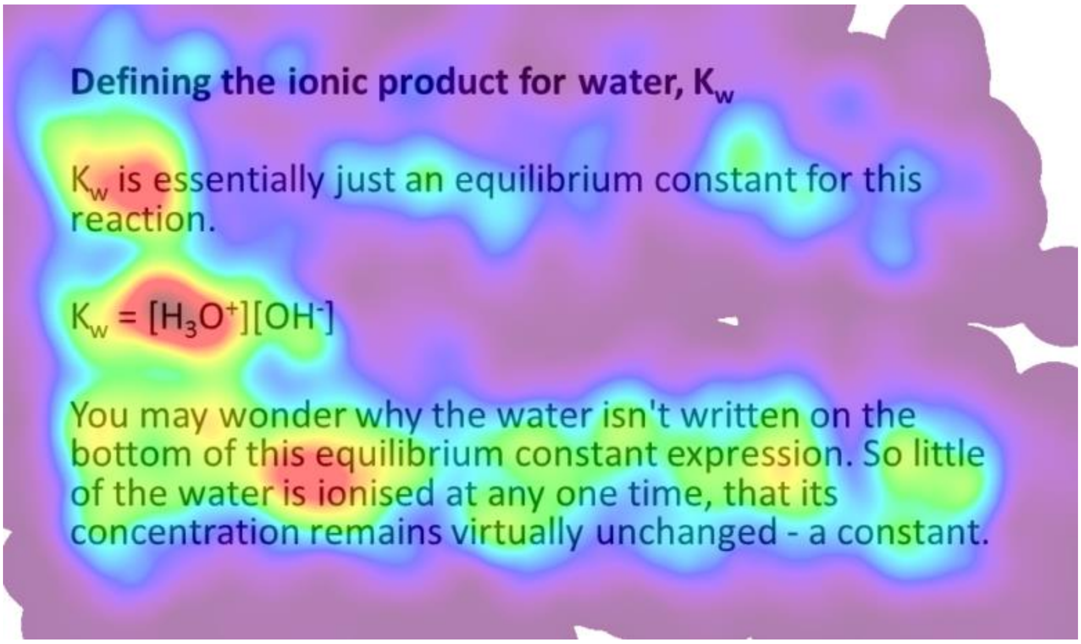
Figure 5.31 November Red sub-group heat map for "*Defining the ionic product for water K_w*" slide



n = 14

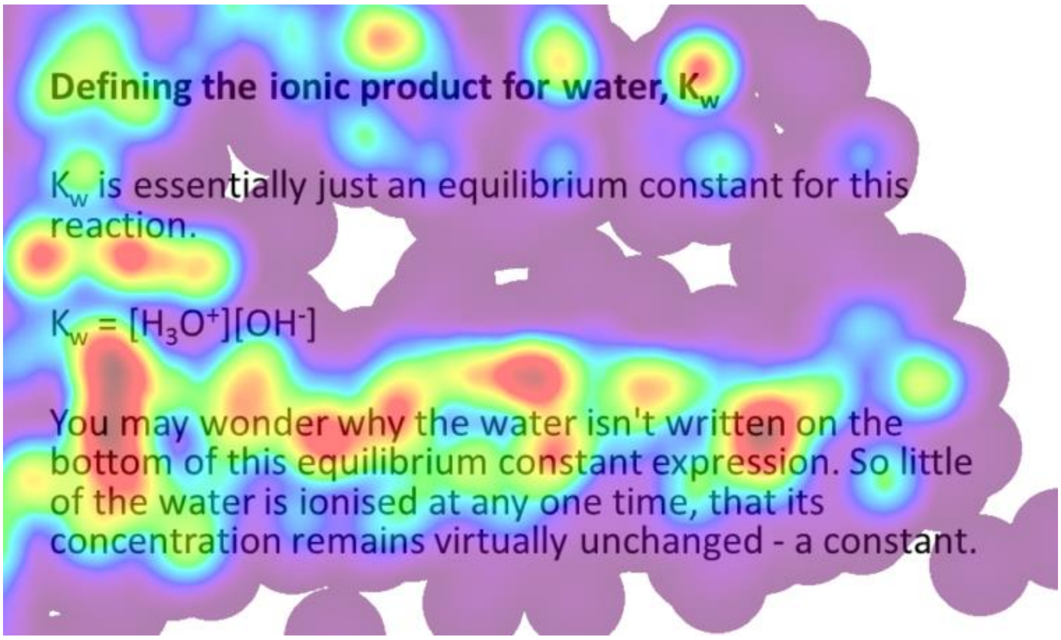
Figure 5.32 November Green sub-group heat map for "*Defining the ionic product for water K_w*" slide

In April, the Red sub-group once again showed focus on the symbolic language of K_w and the equilibrium constant impression (Figure 5.33). This is also evident in the April result for the Green sub-group (Figure 5.34) although there appears be an alignment issue in this instance.



n = 3

Figure 5.33 April Red sub-group heat map for "*Defining the ionic product for water K_w*" slide



n = 10

Figure 5.34 April Green sub-group heat map for "*Defining the ionic product for water K_w*" slide

Green sub-group students focus attention on ΔH *+ve* in the "*effect of temperature*" slide in November and April (Figure 5.27 and 5.30) whilst Red sub-group students did not (Figure 5.25 and 5.29). This suggests that Green sub-group students recognised the importance of this symbol but it was overlooked by Red sub-group students.

5.9.4 Scientific vocabulary, non-technical vocabulary and unfamiliar phrases

The most significant non-technical word in this task was *strong* in the context of a strong acid in the "*important equilibrium in water*" slide. In November, Green sub-group students focused on this word (Figure 5.24) more specifically than the Red sub-group students (Figure 5.23). This suggests that Green sub-group students recognised the significance of the word for the explanation. In April, Red sub-group students showed increased focus on this word (Figure 5.27) suggesting that its significance was now recognised.

In November, the scientific word *hydroxonium* had not yet been introduced and both sub-groups focussed eye attention on the word (Figure 5.25 and 5.26). This pattern is repeated in April (Figure 5.29 and 5.30) with Red sub-group students showing more intense focus. This may suggest that Red sub-group students were taking longer to interpret the meaning of the word.

Red sub-group students focus eye attention on the phrase "*net effect*" in the "*important equilibrium of water*" slide (Figure 5.23) whilst Green sub-group students do not (Figure 5.24). This may reflect a lack of familiarity with this phrase for some Red sub-group students that may affect text comprehension.

5.9.5 Saccades and Regressions

Saccades are rapid movements that move the eye from one place to the next. Skilled readers typically move about seven to nine letter spaces with each saccade. These saccades are separated by pauses known as fixations (which typically last 200-250 msec). It is during the fixation that new information is encoded (Rayner et al., 2006; Chapter 2, Section 2.9, p 67). Green sub-group students demonstrate this pattern in some of the slides. For example in the second paragraph of the "*important equilibrium of water*" slide in November (Figure 5.24) eye focus jumps from the start of the sentence from "*however*" to "*hydroxonium*" and then to "*strong*". Also in the "*defining* *the ionic product for water, K_w*" slide (Figure 5.32), the final paragraph shows eye focus jumping from "*may*" to "*why*" to "*written*" to "*bottom*". Regressions refer to a saccade that moves the eye backward in the text to read material that has previously been encountered. When readers encounter more difficult words or syntactically complex sentences then fixations tend to get longer, saccades shorter and there are more regressions (Rayner et al., 2006). This could explain the more widespread eye focus shown by Red sub-group students in the first paragraph of the "*important equilibrium in water*" slide (Figure 5.23) for example.

5.10 Summary

This chapter has detailed the results of the CLDT for cohort AY23. These results have been analysed in detail to track changes in responses across Year 0 and in relation to academic outcomes. Cohort AY23 demonstrated weaknesses across all sections of the CLDT. Lowest scores were recorded in the word choice and word family sections at the start and end of Year 0. Large effect sizes were recorded for the Red and Green sub-groups. CLDT scores for the Red sub-group remained significantly different in five sections at the end of Year 0 indicating a continued chemical language deficit. Some specific items remained problematic for Red sub-group students at the end of Year 0 such as the equivalence of H_2O and OH_2 (symbolic section) and the meaning of *solution, salt, neutral* and *saturated* (non-technical section). Red sub-group students were more likely to fail Year 0 chemistry exams and were less likely to be successful when progressing to Year 1 than Green sub-group students.

The results of the eye tracker study indicate that Red sub-group students show more widespread eye movements and regressions than Green sub-group students. This may reflect weaker chemical language knowledge, making it more difficult to transition between macroscopic, sub-microscopic and symbolic levels. Data also indicate avoidance of symbolic language and lack of awareness of significant words by Red sub-group students suggesting weaker chemical language comprehension ability than the Green sub-group students. The possible effect of different sample sizes was discussed. The next chapter analyses student interview data and use of chemical language in explanations of scientific scenarios.

Chapter 6

Findings from the semi-structured interview data

This chapter analyses the responses of the six interview students to three different scientific scenarios. Ferne, Linda, Evan, Adam, Neil and Kirsty provided responses to the states of matter and amount of substance scenarios whilst Ferne and Linda also responded to the benzene scenario. The scenarios and model answers are explained in Chapter 4, Section 4.11.1, p. 129. Student responses are analysed for developments in language usage during Year 0 and undergraduate year 1, 2 and 3. Data are analysed for usage of sub-microscopic language, chemical language diagnostic test (CLDT) components, misconceptions and chemical interlanguage.

6.1 Developments in language usage during Year 0

This section discusses the interview data in relation to Research Question 2: In what ways does potential undergraduates' understanding of chemical language develop during a one year, full-time foundation programme?

6.1.1 The states of matter scenario

This section analyses the responses of the six interview students to the states of matter scenario during Year 0 (Chapter 4, Section 4.11.1, p. 129). This scenario provided an opportunity to demonstrate the application of sub-microscopic vocabulary such as *hydrogen bonding*, *polarity* and *electronegativity* to explain macroscopic observations relating to changes in state. Responses at the beginning of Year 0 can be classified into two groups. Two students (Adam and Kirsty) provided very limited explanations of the scenario recording low correct chemical language (CCL) scores of three and five respectively. Words used were everyday scientific terms such as *liquid, energy* and *evaporating*. Adam and Kirsty were unable and/or unwillingly to provide an explanation using sub-microscopic language. Adam showed knowledge of changes in kinetic energy but struggled to recall the word *kinetic* (Appendix 11, November 2012, Comments 20 to 22). Adam's language skills restricted his ability to provide an explanation at the level of his internal understanding (Postman and Weingartner, 1971; Chapter 2, Section 2.2, p. 31). This limited language ability affected his ability to participate in classroom activities and discussions.

Kirsty demonstrated knowledge of particular movement but when asked to explain the effect of temperature on the water particles she responded "*I think that's about as much as I am going to be able to answer*" (Appendix 13, November 2011, comment 12). She lacked knowledge to develop her response further. This represents the limit of her zone of actual development (ZAD) (Vygotsky, 1962).

Towards the end of Year 0, Adam and Kirsty used correct chemical language increasingly frequently, giving CCL scores of ten and thirteen respectively. Adam used some sub-microscopic language and referred to molecules moving faster (Appendix 11, May 2013, Comment 12). His vocabulary, however, remained limited and he was, once again, unable to recall the word *kinetic* (Comment 16 to 26). He had not acquired this vocabulary during the intervening six months. He also looked up *hydrogen bonds* on his smartphone indicating this word was also not in his vocabulary (Comment 34). Adam misunderstood the meaning of *hydrogen bond* as a bond between two hydrogen atoms (Comment 34). He also did not understand the meaning of *dipole* (Comment 49 - 50) and made no reference to *electronegativity*. Therefore, by the end of Year 0, Adam had not acquired the relevant vocabulary to provide a sub-microscopic explanation for the states of matter scenario.

At the end of Year 0, Kirsty, used relevant sub-microscopic language and referred to *hydrogen bonding* and *van der Waals' bonding* (Appendix 13, April 2012, Comment 10). She was initially unsure which type of bonding was correct but decided on *hydrogen bonding* (Comment 14). She tried to provide an explanation of hydrogen bonding but became confused with incorrect use of *electronegative* which resulted in her losing confidence in her explanation and giving up. She said:

"*Actually it's the hydrogen bonding between them in the molecules so the attraction between oxygen and hydrogen of separate because the oxygen is more electronegative and it will slightly attract hydrogens from a different molecule, erm, and then as it goes to liquid I don't know, less energy. I am not sure*" (Comment 14).

She confused permanent dipoles due to differences in electronegativity with attraction between atoms in separate molecules. *Negative* would have been a more appropriate word than *electronegative*. Kirsty demonstrated more confidence than at the start of Year 0 (confidence rating increased from 2 to 3) in developing her explanations. Difficulties in using the relevant scientific words such as electronegativity make it more challenging to operate in her zone of proximal development. That is to say, to perform successfully within a social constructivist environment requires the student to have confidence in their understanding and usage of the relevant vocabulary. The use of *slightly* in the phrase "*slightly attract hydrogens*" is interesting. Hydrogen and oxygen atoms were not consciously described as *slightly attracting* during teaching, so this may be a modification of the commonly used phrase *slightly positive* or *slightly negative* when describing partial charges on atoms in a polar covalent bond. This is an example of Kirsty demonstrating chemical interlanguage that combined aspects of explanations she had learned (Section 6.5, p. 206). Kirsty also demonstrated understanding of differences in electronegativity between hydrogen and oxygen causing a dipole (Comment 18) but was unable to provide an explanation of what the word means (Comment 20). This is another example of chemical interlanguage. Therefore, at the end of Year 0, Kirsty acquired relevant sub-microscopic vocabulary, with her explanations at an interlanguage stage moving towards an expert explanation.

Four students (Ferne, Linda, Neil and Evan) provided explanations at the sub-microscopic level and had higher CCL scores of seven, eight and nine respectively at the start of Year 0. These students used every day scientific words such as *liquid* and *gas* but also referred to *molecules, particles, bond* and *vibrates*. Ferne, for example, referred to "*liquid water which is molecules I think closely packed and they slide around*" (Appendix 1, January 2014, Comment 8). However, none of these students demonstrated knowledge of intermolecular forces or used words such as *dipole, hydrogen bonding* or *electronegativity*.

At the end of Year 0, these students increased their CCL scores to fifteen (Ferne), thirteen (Linda), seventeen (Evan) and sixteen (Neil). The students used relevant sub-microscopic vocabulary such as *hydrogen bonding, dipole, negative, electronegative* and *intermolecular*. Linda provides a near "*expert*" explanation of the formation of polarity in a water molecule in Comment 7 (Appendix 4, May 2014):

"*Because water is a dipolar molecule meaning that the oxygen is more electronegative and pulls the electrons from the hydrogen closer which makes it more negative nearer the oxygen*"

This level of response demonstrates model based reasoning and may be classified as a Level 4 response as described by Gunckel et. al. (2012; Chapter 2, Section 2.7.2, p. 62).

This contrasts with an explanation of polarity three months earlier (Appendix 4, February 2014, Comment 20) that did not use electronegativity correctly:

"*In the molecule, yeah in the bond, yes the two electrons are negative and the nucleus is positive then the negative is shared between the oxygen and the hydrogen because of the electronegativity*".

Therefore, from February to May, Linda demonstrated successful chemical language acquisition. She developed understanding of electronegativity and used this correctly in her explanation.

In May 2014 (Appendix 1, Comment 4) Ferne demonstrated good use of *hydrogen bonds, intermolecular forces* and *lone pairs of electrons*. Evan (Appendix 7, March 2014, Comments 12 to 14) also showed knowledge of *intermolecular forces* and *hydrogen bonding*. However, he was unable to provide an explanation of *polarity* (Comment 20). It is unclear whether this was because he did not understand the concept or did not have vocabulary (i.e. *electronegativity*). Neil (Appendix 9, May 2013, Comments 10 - 18) correctly described the dipole in a water molecule but was not able to explain this in terms of electronegativity.

Student	Ferne			Linda			Evan		Neil		Adam		Kirsty	
Year 0 Interview	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Words*														
dipole					1	1		1		1				1
electrons		1	1		1	1		1		1				
electronegativity						1								
hydrogen bonding		1			1	1			1	1				1
oxygen		1	1		1	1				1		1		1

* "1" indicates correct usage.

Table 6.1 Usage of five sub-microscopic words from the states of matter scenario

Table 6.1 shows the incidence of correct usage by the interview students of five different relevant sub-microscopic words for this scenario. Very few of these words were used at the start of Year 0 but increased usage was apparent by the end of Year 0. Only one interview student (Linda), however, was able to use the word *electronegativity* correctly by the end of Year 0.

6.1.2 The Amount of Substance scenario

This section analyses the responses of the six interview students to the amount of substance scenario during Year 0 (Chapter 4, Section 4.11.1, p. 129). At the start of Year 0, Evan used relevant sub-microscopic chemical language to explain the scenario (CCL score = 10). He referred to *relative atom* (sic – atomic) *mass, Ar, mole, atomic number, protons, electrons* and *neutrons*. He used words appropriately but demonstrated misunderstandings (Section 6.4, p. 202). He mistakenly stated that the relative atomic mass for the sodium is greater than lead (Appendix 8, November 2013, Comment 2 and 4).

The other five interview students (Ferne, Linda, Adam, Neil and Kirsty) used less chemical language to explain the scenario (CCL scores from 1 to 7). Their vocabulary was limited to *atoms*, *mass, particles, substance* and *grams*. Ferne referred to atoms being *bigger* and *containing more protons* (Appendix 2, November 2013, Comment 4) but was unable to use *relative atomic mass* to explain the difference between atoms of the two elements. Neil also referred to atoms being *larger* (Appendix 10, November 2012, Comment 4) but was unable to explain this in detail. Linda recognised lead was a larger atom and had a *higher atomic mass* (Appendix 5, November 2013, Comment 10). She referred to the *weight* of the substance rather than *mass*. Adam was unaware of lead (Appendix 12, November 2012, Comment 4) but understood that the lead atoms were *bigger* (Comment 10). He considered the greater number of electrons in a lead atom to be significant to explaining the scenario. Kirsty was not asked the scenario specifically at the start of Year 0 but participated in a related discussion about calculating amount of substance in moles (Appendix 14, November 2011). She explained how she finds the rhyme "*grams over rams*" useful (Comment 2), whereas A_r is confusing as she was uncertain of its meaning.

At the end of Year 0, Evan consistently used *relative molecular mass* (Appendix 8, May 2014, Comment 2) rather than *relative atom* (sic – atomic) *mass* which he had used previously (November 2013, Comment 2). After a discussion about the difference between atoms and molecules, Evan corrected his language and referred to *relative atom* (sic – atomic) *mass*. He referred to *molecular* rather than *molecule* but when questioned he understood the difference between *molecule* (noun) and *molecular* (adjective) (Comment 16). He did not demonstrate significant progress in his use of sub-microscopic language by the end of Year 0 (CCL = 5).

Three students showed improved usage of chemical language such as *moles* and *molar mass* (Ferne, Linda and Kirsty). Adam and Neil showed limited progress. Ferne, Linda, Kirsty and Adam referred to *relative molecular mass*. Ferne used *relative molecular mass* (Appendix 2, March 2014, Comment 6) but corrected herself when questioned (Comment 8). Linda initially referred to *atomic mass*, checked herself as to whether it should be *molecular* before deciding that *atomic mass* was correct. She talked about *molecules of lead and sodium* (Appendix 5, May 2014, Comment 2) and *molecular mass of lead* (Comment 24). Kirsty referred to *relative molecular mass* (Appendix 14, April 2012, Comment 2), did not correct it and referred to *molecules of carbon* (Comment 12) and *hydrogen* (Comment 18). Adam used the phrase *molecule mass* (Appendix 12, May 2013, Comment 8) but corrected to *atoms* when questioned (Comment 10). This incorrect and systematic use of *molecule* rather than *atom* is an example of chemical interlanguage and is discussed further in Section 6.5 (p. 206).

Adam had a CCL score of 1 at the start of Year 0 and this increased to 3 by the end of Year 0. He was able to use the word *electron* appropriately at the end of Year 0 but did not use any further relevant chemical language. Hence, as with the states of matter scenario, his limited language skills restricted his ability to develop detailed explanations and understanding. The extent of internal understanding compared to his ability to provide an external explanation is hard to determine (Postman and Weingartner, 1971; Chapter 2, Section 2.2, p. 31). Ferne extended her chemical language usage with *moles* and *molar mass* although incorrectly stated that the molar mass of lead was less than sodium (Appendix 2, March 2014, Comment 10). She recalled *Avogadro's constant* (Appendix, 2, March 2014, Comment 12). Linda continued to demonstrate confusion as to whether *weight* or *mass* was the correct word to use (Appendix 5, May 2014, Comment 2). Therefore, although their use of sub-microscopic vocabulary had developed since the start of Year 0, they had difficulty providing coherent explanations for the scenario. Neil recognised that heavier atoms had a higher proton and neutron content (Appendix 10, May 2013, Comment 2) although he incorrectly described sodium as heavier than lead. He recognised the errors and corrected this when prompted (Comment 4). He was unable to extend the explanation to *relative atomic mass* and *moles*.

6.1.3 The Benzene scenario

This section analyses the responses of two interview students to the benzene scenario during Year 0 (Chapter 4, Section 4.11.1, p. 129). In her initial explanation (Appendix 3, January 2014), Ferne used a substantial amount of chemical language (CCL = 16). She referred to *delocalised electrons* and *electron clouds* appropriately (Comment 4, Line 5 and 8) and attempted to use *sigma* and *pi bonds* (Comment 4 line 3), demonstrating partial understanding. Her use of *electronegativity* (Comment 4, Line 11) was incorrect (electron density would have been a more appropriate term). At Comment 6, an appropriate phrase is used "*induce a dipole*", but this is confused with *electronegativity*. Ferne may have confused *electronegativity* with *electron density* indicated by the connection with *induce a dipole* (Comment 6). The incorrect use of *electronegativity* correlates with the states of matter scenario (Section 6.2.2, p. 192). Ferne was unable to develop her explanation further. At Comment 16, Ferne made her third use of *delocalised* with the phrase *delocalised bonds*. At Comment 20, Ferne was unable to develop an explanation of the reaction of phenol and does not try to use appropriate terminology. Ferne demonstrated a willingness to explain the scenario and use to try to use appropriate terminology.

Linda's initial explanation was more limited in scope. She showed some awareness of the structure of benzene and mentioned *pi bonds* (Appendix 6, January 2014, Comment 2). She stated "*the electrons are spread out all around the ring*". She was able to demonstrate understanding without using more scientific vocabulary such as *delocalised*. She was aware that cyclohexene is an alkene and, therefore, contains a carbon - carbon double bond (Comment 4). She mentioned *polarity* and had an idea of positive and negative charges (Comment 8) but was unable to expand on how this is produced. She was aware of the structural difference and the presence of an OH group in phenol (Comment 16) but was unable to explain how this affects the molecular structure.

At the end of Year 0, Ferne used a range of relevant sub-microscopic chemical language when discussing the reactivity of phenol (Appendix 3, May 2014). She referred to *delocalised electrons, electron cloud, curly arrows* (Comment 9) and *inducing dipoles* (Comments 11 and 13) but the explanation is disjointed and she incorrectly referred to electrons from the oxygen atom reacting (sic – interacting) with delocalised electrons

(Comment 9 line 8). At Comment 17 (Line 4) Ferne demonstrated good usage of the term *delta negative* (rather than saying *negative*). Ferne had successfully incorporated some of the sub-microscopic vocabulary for this scenario during Year 0 but could not produce a coherent explanation by the end of Year 0.

Linda applied chemical language to explain the scenario correctly (CCL = 20) and incorrectly (ICL = 4) at the end of Year 0 (Appendix 6, May 2014). At Comment 2, she explained the structure of benzene and applied terms such as *delocalised* and *sigma* appropriately. She was less confident about using *electrophilic* (Comment 2 line 7) and incorrectly applied *polarity* (Comment 2 line 3). At comment 14, Linda tried to apply the term *electronegativity* but it is not appropriately used in this context. Linda had also successfully acquired some sub-microscopic vocabulary but had difficulties providing an explanation at the end of Year 0.

6.2 Language usage beyond Year 0

Upon completing Year 0, the students progressed to their undergraduate programmes where understanding of the scientific knowledge relating the scenarios would be expected and not explicitly taught.

6.2.1 The states of matter scenario

Ferne, Linda and Kirsty studied biomedical sciences. In December 2014, at the end of her first term in Year 1, Ferne introduced thermodynamic ideas that she would have been learning (Appendix 1, Comment 2 and 6) using *entropy* and *enthalpy* (Comment 2, Line 6). These words were used generally, and she was unable to develop a meaningful explanation (Comment 6). She correctly recalled *hydrogen bonds* (Comment 12) and used *electronegative* correctly (Comment 14 and 22) although she drew an electron cloud incorrectly from the oxygen atom on one water molecule to the hydrogen atom on another. She was able to correct this after prompting and used *dipole* appropriately (Comment 26). In June 2015, Ferne provided a response at the sub-microscopic level and used words such as *electronegative* (Comment 20), *electron cloud* (Comment 24) and *hydrogen bonding* (Comment 34). This indicates that Ferne had successfully incorporated this sub-microscopic vocabulary and was able to use it successfully to provide explanations.

At the end of the first term of Year 1 (December 2014), Linda tried to use thermodynamic vocabulary in her explanation. She used a systematic phrase "*thermodynamically favourable over thermodynamically unfavourable*" (Comment 4, Line 7) but was unable to elaborate. She referred to hydrogen bonds reforming (Comment 4, Line 6). In June 2015, she described polarity in the water molecule and used *hydrogen bonds* (Comment 2, Line 6), *nonpolar* (Comment 6, Line 5) and *electronegativity* (Comment 10) appropriately. Linda had successfully incorporated sub-microscopic vocabulary.

At the end of Year 1 (Appendix 13, June 2013), Kirsty also referred to entropy (Comment 4) and explained about increasing disorder. In August 2014 (end of Year 2) she provided a confused explanation of a water molecule when she stated "*the electrons never staying still although it being a neutral charge the electrons moving which was causing negative and positive charges at points on the molecule*". She described differences between the nucleus of an oxygen atom and a hydrogen atom making an oxygen atom relatively positive (Comment 24) and recalled *electronegativity* although she was uncertain if it was the correct word (Comment 26). She was unable to recall which atom is partially positive and which is partially negative (Comment 42). At the end of Year 3 (June 2015), Kirsty was unable to recall the name of the intermolecular forces (Comments 17 and 19) and was unable to explain electronegativity (Comment 27). She had understanding of the words and used them during her studies (Comment 29) but was not required to explain them. As Kirsty progressed, she could no longer provide an explanation for the scenario. The vocabulary, however, was used in other contexts.

Evan and Adam progressed to study Chemistry. Evan used a range of sub-microscopic language at the end of the first term of Year 1 (Appendix x, December 2014). Initially, he referred to *van der Waals' forces* holding water molecules together (Comment 8) but then corrected to *hydrogen bonds* (Comment 12). He incorrectly referred to them as *dative bonds* (Comment 16). He mentioned *electronegativity* after being prompted (Comment 26). He introduced new vocabulary from Year 1 appropriately with the use of *electrocentre* (Comment 28). Evan could use sub-microscopic vocabulary but had significant misunderstandings (Section 6.4, p. 202). Adam could not describe interactions between water molecules towards the end of Year 1 (Appendix 12, March

2013, Comment 22) indicating that he could not access relevant sub-microscopic vocabulary.

Neil progressed to study medicine. At the end of Year 2 (Appendix 9, June 2015), Neil struggled to recall relevant sub-microscopic vocabulary to explain the states of matter scenario. He initially described the intermolecular forces as *van der Waals' forces* (Comment 8) and he confused this with a description of covalent bonding (Comment 16). He was unable to recall *covalent bond* (Comment 24) or *electronegativity* (Comment 37). Two years after completing Year 0, Neil was unable to recall sub-microscopic vocabulary or an explanation for this scenario.

6.2.2 The amount of substance scenario

At the end of the first term of Year 1 (Appendix 2, December 2014), Ferne referred to *atomic weight* (Comment 6) and then corrected herself. She used weight, which was active vocabulary that term, Ferne commented how the lecturers use *weight* rather than *mass* (Comment 6). Eiss (1961; Chapter 2, Section 2.4, p. 46) recognised the difficulties caused by words such as *weight* having different meanings in separate sciences. Ferne used *amu* and *atomic mass units* (Comment 18) and *Daltons* (Comment 28) as newly acquired vocabulary. She applied relevant sub-macroscopic vocabulary such as *moles* and *Avogadro's constant* (Comment 12) appropriately and referred to *atomic mass* without using *relative* (Comment 16). At the end of Year 1, (June 2015) she continued to demonstrate usage of relevant vocabulary such as *mole*, and *Avogadro's number*. She referred to *atomic mass* without using *relative* (Comment 2, Line 5). This systematic dropping of *relative* from the phrase *relative atomic mass* is an example of chemical interlanguage (Section 6.5, p. 206).

In December 2014, the end of the first term in Year 1 (Appendix 5). Linda discussed the content of a Powerpoint® slide explaining amount of substance and reaction stoichiometry (Chapter 2, Box 6, p. 50). The text includes the phrase *gram molecular weight,* which would not have been used in Year 0. When asked about the meaning of the phrase, Linda provided a confused response (Comment 19) but had an idea that it was the weight of a molecule relative to carbon twelve. When asked what would be an equivalent word used in Year 0, Linda incorrectly suggested *moles* (Comment 25). This arose because the slide text is "*this is the gram molecular weight, or mole*". After further discussion she correctly decided on *molar mass* (Comment 35). In June 2015 (end of Year 1) she correctly used sub-microscopic words such as *proton* and *neutron* (Comment 2) but incorrectly referred to *atomic number* rather than *relative atomic mass* (Comment 10). She used *mole* appropriately but considered *Dalton* to be equivalent (Comment 4 – 6), indicating confused understanding of these words.

At the end of Year 1 (Appendix 14, June 2013), Kirsty interchanges the *atomic number* and *relative atomic mass* (Comment 2). She referred to *Avogadro's constant* and *carbon 12* (Comment 4) but struggled to recall detail (Comment 6). In June 2015 (end of Year 3), Kirsty referred to *protons* and *neutrons* (Comment 34) and recalls *mole* after prompting (Comment 42) but is unable to provide an explanation (Comment 46). She is unable to recall the correct value of *Avogadro's constant* (Comment 46, Line 7) and referred to iron rather than carbon (Line 10).

In February 2014, mid-way through Year 1 (Appendix 10) Neil referred to *atomic mass* without using *relative* (Comment 2). He recalled the mole mass equation was relevant (Comment 6) but was unable to explain how to use it (Comment 8). At the end of Year 2 (June 2015), Neil recalled *electrons* and *neutrons* but referred to *positrons* rather than *protons*. This error seems to be caused by *positrons* being an active word in a medical context (Comment 10). Neil referred to *weight* rather than *mass* (Comment 10 and 24). He recalled *moles* but could not explain its meaning (Comment 24). At the end of Year 1 (Appendix 10, June 2015) he correctly used *mole* and *molar mass* but incorrectly referred to *molecular mass* (Comment 4). In March 2014, towards the end of Year 1, Adam referred to *relative mass* (Appendix 12, Comment 14) omitting *atomic*.

6.2.3 The benzene scenario

Ferne and Linda responded to the benzene scenario at the end of Year 1 (June 2015). Ferne correctly recalled *sigma* and *pi bonds* (Appendix 3, Comment 6). She referred to *electron cloud* (Comment 12, Line 4) but recalled mechanism names as *electron substitution* and *electron addition* rather than *electrophilic* (Comment 22). This is possibly an example of chemical interlanguage backsliding (Section 6.5.4, p. 210). Linda referred to *dislocated electrons* (Appendix 6, Comment 2) rather than *delocalised electrons* and incorrectly used *electronegativity* (Comment 8). Both students struggled to explain the scenario.

6.3 Use of language components assessed in the CLDT

In this section interviews in Year 0 are discussed in relation to language usage relevant to the CLDT sections. Ferne, Linda and Evan were part of the AY23 cohort and, therefore, have CLDT scores. Adam, Neil and Kirsty completed Year 0 before the CLDT had been developed, so do not have CLDT scores.

6.3.1 Word choice and word family sections

Initial CLDT results show low scores for the word choice and word family sections (Figure 5.2, p. 141). The states of matter scenario used the same vocabulary as the kinetic word family section of the CLDT. The CCL scores for the initial explanations of the states of matter scenario range from three to eight, supporting low scores recorded in the October CLDT. Linda, with the highest CCL score of eight, (Appendix 4, November 2013) used words such as *kinetic energy, heat* (Comment 2) and *condensation* (Comment 10). In the October CLDT she scored 20% in the kinetic word section. Evan had a CCL score of eight in November 2013 (Appendix 7). He used words such *as kinetic energy, vapour, vibrate* and *liquid* (Comment 4). He scored 0% in the kinetic word section of the October CLDT suggesting the CLDT did not correctly capture Evan's knowledge of kinetic theory words at the start of Year 0. Adam, with the lowest CCL score of 3, used *gas* incorrectly when referring to condensation and was unable to pronounce *kinetic*. There is no CLDT data for Adam as he commenced his studies prior to its implementation. At the end of Year 0, CCL scores increased to between ten and twenty six. Adam, with the lowest CCL score of ten, used words such as *gas, liquid* (Appendix 11, May 2013, Comment 2) and *temperature* (Comment 8) but still struggled to use *kinetic* (Comment 16). Linda, with a CCL score of 26 at the end of Year 0, used a range of vocabulary such as *gaseous, diffuse, condensation, hydrogen bonds* and *polarity*. Linda's CLDT kinetic word family section scores show an initial increase from 20% (October) to 50% (December) but then fell to 25% in May (Appendix 15). Ferne's CCL scores increased from eight to twenty four from January to May. Her CLDT kinetic word scores for December was 100% and 30% in May. Evan's CCL scores increased from eight to seventeen at the end of Year 0 and his CLDT kinetic word scores were 0% in October, 80% in January and 45% in May. The May CLDT scores do not reflect the improvements in chemical language usage at the end of Year 0. This could be due to the fact that the May CLDT for the 2012/13 (AY2) cohort was the first time the CLDT was completed online. The students had completed a paper version in October and December. The change in format may have affected some students' responses to this section (Chapter 4, Section 4.8.3, p. 111).

The word choice section of the CLDT explores student knowledge of scientific words. Although the words in this section are indirectly relevant to the interview scenarios, data provide examples of everyday or scientific word choice by the students. For example Linda (Appendix 4, November 2013, Comment 2) changed the word *top* to *surface* when referring to the coffee cooling down. She also used *vibrating* rather than the simpler *moving* when describing molecular movement (Comment 12). In February 2014 (Appendix 4, Comment 2) she stated that water molecules "*in gaseous form they, er, transfer, diffuse into the rest of the room"*. She is conscious of word choice, changing *transfer* to the scientific *diffuse*. This suggests good understanding of *diffuse*. Within the same Comment, Linda stated that the water molecules "*overcome their hydrogen bonds and they split into the air"*. In this instance, *separate* would have been a more appropriate word choice than *split*. In May 2014 (Appendix 4, Comment 5) Linda referred to *hydrogen bonds* as "*continuously break and reattach*" where *reform* would have been the more appropriate word choice. By June 2015, Linda had acquired use of this word and she stated that the "*hydrogen bonds reform*" (Appendix 4, Comment 2, Line 8). In Comment 6 she stated that the "*charge is not distributed equally so certain parts of them* [water molecules] *are either more negative or more positive*". This compares with February 2014 when she referred to "*more concentration of negative"* (Comment 6). These examples suggest improvements in her usage of scientifically appropriate language and may be considered examples of chemical interlanguage (Section 6.5, p. 206). Linda's CLDT word choice section scores were 20% in October, 50% in December and 30% in May indicating that she still had difficulty with this section at the end of Year 0. Ferne showed steady improvement in her CDLT word choice scores from 30% in October, 40% in December and 60% in May. In interview she provided examples of scientific word choice. For example in the benzene scenario, in January 2014 (Appendix 3) she referred to a "*species coming along*" in the context of a molecule approaching a carbon carbon double bond. In the states of matter scenario in March 2014, she referred to hydrogen bonds breaking and reforming (Appendix 1, Comments 12, Line 8 and Comment 18, Line 6).

Evan used *vibrate* in his initial interview although this is at the macroscopic level as he referred to "*vapour water*" rather than *water vapour molecules*. (Appendix 7, November 2013, Comment 4). In December 2014 (Appendix 7), Evan shows progression with reference to "*water molecular* [molecules]" (Comment 2, Line 3) and used *vapour* rather than *vapour water* (Comment 2, Line 9). In June 2015, Evan referred to vague "*matter in the coffee*" (Appendix 7, Comment 2, Line 4) rather than *molecules* which suggests a language usage regression. In March 2014, Evan referred to water molecules being a "*bit negative and a bit positive*" rather than the more academic *partially* or *slightly negative*. At the end of the first term of Year 1 (Appendix 7, December 2014, Comment 28) Evan demonstrated acquisition of new vocabulary with reference to *electrocentre* when referring to the nucleus of an oxygen atom. At Comment 30, Evan described greater electron density around the oxygen atom and corrected his word choice from *cause* to *induce* in the phrase "*will have more electron density and cause and induce that become delta minus*". However, his word choice is not an improvement with neither *cause* or *induce* required for a correct explanation (*resulting in* would be more appropriate). *Induce* is typically used to describe a region of high electron density inducing a dipole in a molecule such as bromine when approaching the carbon carbon double bond. Evan demonstrates interlanguage with partial understanding of how to apply the word. Evan's CLDT scores for the word choice section were 20% in October, 10% in December and 40% in May (Appendix 15).

Neil referred to "*the oxygen a bit negative and hydrogen is a bit positive*" (Appendix 9, May 2013, Comment 12) and used the phrase "*electrons are more around the oxygen atom*" (Comment 14). In June 2015, Neil struggled to recall the sub-microscopic explanation for the scenario but, after prompting, repeats the phrase "*a bit positive*" which he developed to "*and it's that slight positive force on the hydrogen atoms*" (Comment 44). He incorrectly used *force* rather than *charge*.

In her initial interview, Kirsty stated that water particles, when they become steam, "*move about, spread out*" rather than *diffusion* (Appendix 13, November 2011, Comment 12). In June 2013, Kirsty used the informal word *bang* rather than *collide* (Comment 10) when referring to water molecules being spaced out and less likely to collide into each other. Kirsty made an unusual word choice of *gas form* and *liquid form* in June 2015 (Comment 4) when the simpler *gas/liquid* or the more scientific *gas/liquid phase* would have been appropriate. Adam referred to *gas form* and *liquid* *form* (Appendix 11, May 2013, Comment 2). At Comment 12, he referred to an "*increase in temperature*" but uses "*temperature go down*" rather than *decreases*. In the previous interview (Appendix 11, November 2012, Comment 22) referred to "*the kinetic energy is decreased*". This suggests that Adam fluctuates between scientific and colloquial language (Lemke, 1990; Chapter 2, Section 2.3, p. 42).

6.3.2 The Fundamentals section

The CLDT Fundamentals section (Chapter 4, Section 4.8.3, p. 111) tested understanding of words such as *atom, molecule, element* and *compound*. The amount of substance scenario provided opportunities to explore student understanding of *atom* and *molecule*. Several students used *relative molecular mass* rather than *relative atomic mass* such as Evan (Appendix 8, May 2014, Comment 2 and June 2015, Comment 4). This error did not prevent the student from providing an appropriate response to the scenario. When trying to explain the difference between *atom* and *molecule*, Evan referred to different numbers of atoms:

"*Atom and molecule, oh molecule it mean er, it can consis, consist of er, different number of er, atoms. I think lead is to have atom not the molecule and I think sodium as well*" (Appendix 8, May 2014, Comment 10)

He does, however, state that *atom* rather than *molecule* is the correct word suggesting he understands the meaning of the words. Evan achieved high scores in the CLDT fundamentals section (October – 83%, December and May – 100%) suggesting that he has good understanding of these words. The interview indicates that Evan had linguistic limitations that affected his ability to articulate an explanation clearly.

Adam demonstrated similar difficulties to Evan when trying to explain the difference between atoms and molecules:

"*Er, atoms just have one, one er, one atoms is one things but the molecules is er, er, like er, made by the atoms*." (Appendix 12, May 2013, Comment 12).

Linda scored 100% in the CLDT fundamentals section in October, December and May but referred to *molecules* rather than *atoms* of lead (Appendix 5, May 2014, Comment 2 and June 2015, Comment 2 and 10). She demonstrated understanding in the CLDT but her language usage in interviews was imprecise, which affected the quality of her explanations. Kirsty demonstrated repeated use of *molecules* rather than *atoms* (Appendix 14, April 2012, Comments 2, 12 and 18 and June 2015, Comment 4). When asked to explain the difference between *atoms* and *molecules* she provided a simple explanation:

"*I have the idea of an atom as a single thing and molecule being more than a single thing. So a molecule of something being five of that*". (Appendix 14, June 2015, Comment 24).

Ferne demonstrated correct use of *atoms* (Appendix 2, June 2015, Comment 2 and 6). She scored 50% in the October CLDT fundamentals section and then 100% in December and May.

6.3.3 The Affixes section

The scenarios required the use of words relevant to the affixes section of the CLDT (Chapter 4, Section 4.8.3, p. 111). These were: *intermolecular, dipole, electrophile, hydrogen and cyclohexene*. *Intermolecular* was always used correctly by Ferne and Evan in the states of matter scenario when they provided sub-microscopic level explanations. Ferne referred to *intermolecular bonds* in March 2014 (Appendix 1, Comment 12) and *to intermolecular forces* in May 2014 (Appendix 1, Comment 4). On this second occasion, she emphasised the *inter* prefix when saying *intermolecular* as if to highlight her awareness of the correct prefix. Evan (Appendix 7, March 2014) used both *intermolecular force* (Comment 12) and *hydrogen bond* (Comment 14) appropriately. Neil did not use the word *intermolecular* in his explanations but referred specifically to *hydrogen bonding* (Appendix 9, May 2013, Comment 10). Kirsty also referred to *hydrogen bonding* specifically (Appendix 13, April 2012, Comment 10) at the end of Year 0. Three years later she described "*the bonds holding the molecules together*" (June 2015, Comment 11) when she could have said *intermolecular bonds*. This suggests that this scientific word was not part of her active vocabulary. Linda referred to *hydrogen bonds* specifically rather than *intermolecular forces* (Appendix 4, February 2014, Comment 2, Line 3). Adam does not use *intermolecular* and is only able to refer to *hydrogen bonds* once he looked the word up on his smartphone (Appendix 11, May 2013, Comment 34). This suggests that Ferne and Evan incorporated the word *intermolecular* into their vocabulary whilst the other students did not.

Ferne demonstrated awareness of the *ene* suffix at the end of Year 1 (Appendix 3, May 2015, Comment 28) when she emphasised the *ene* part of *hexene*. She also deduced that *hex* means six (Comment 30) but this required conscious effort rather than being automatic. Ferne had high scores in the affixes section of the CLDT with 90% in October and 100% in December and May indicating good knowledge. Linda scored 55% in the October CLDT, 90% in December and 95% in May. In Year 1, however, she was less able to apply this language skill. In June 2015 she was asked if the *ene* part of *cyclohexene* meant anything to which she responded "*Erm, it is the same group, alkali, no sorry can't remember*." She appeared to be making a connection between *alkene* and *alkali* rather than the meaning of *ene*.

6.3.4 The Non-technical language section

The non-technical language tested in the CLDT is not prevalent in the scenario explanations. The word *weight*, however, was used instead of *mass* in the amount of substance scenario by Ferne, Linda and Neil. Linda was the only student to use *weight* in her initial explanation in November 2013. She stated that "*if an atom is heavier er, then it will, for the same weight be less atoms than to make up the same amount of weight*" (Appendix 5, Comment 10, Line 4). *Weight* was never used in the teaching activity and the other students referred to *mass* in their initial interviews. This is not to say that it is incorrect to refer to weight in the context of one atom being heavier than another. The response indicates that *weight* was an active word for Linda at the start of the course and *mass* had not yet replaced it. At the end of Year 0, Linda questioned whether *mass* or *weight* was the correct word but remained unsure as to word meaning "*actually weight rather than, is mass or weight? What's the difference?*" (Appendix 5, May 2014, Comment 2, Line 5). In Year 1, the word *weight* was used on the Biomedical Sciences undergraduate course in phrases such as *gram molecular weight* (Chapter 2, Box 6, p. 50) and is, therefore, the correct subject specific language to use. Linda had difficulty explaining the meaning of *gram molecular weight* when she states:

"*It is erm, the amount of, erm, er, number of (p2) grams per molecule in the weight that is equal to, er, the same amount of grams in, erm, of carbon, er, isotope twelve*". (Appendix 5, December 2014, Comment 19)

Linda used weight again at the end of Year 1 (June 2015, Comment 2, Line 5). Ferne was studying biomedical sciences so received the same teaching as Linda. She referred to *mass* in Year 0 but used *atomic weight* in Year 1. She was conscious of this and remarks how lecturers used *weight* rather than *mass.* She commented "*Because lead has a lower erm sorry a higher atomic weight sodium has a lower atomic, no sorry, you know what it is these guys here just don't care they say weight rather than mass*" (Appendix 2, December 2014, Comment 6). Confusion between appropriate use of the two words affected the quality of her explanation. She used *mass* in the remainder of her explanation and referred to *mass* in June 2015 (Comment 2, Line 5). Neil used limited chemical language in his explanation and mentions *mass* in February 2014 (Appendix 10, Comment 2). In June 2015 he referred to "*higher molecular weight*" rather than *mass* (Comment 10, Line 3). Neil was studying medicine and this suggests that, within this community of practice, the colloquial use of *weight* was more common and was now incorporated into his active vocabulary.

6.3.5 The Symbolic language section

The scenarios could be explained without reference to symbolic language (Chapter 4, Section 4.11.1, p. 129) and there were limited instances of its occurrence in interviews. Evan used symbolic terminology when he referred to partial charges on water molecules (Appendix 7, December 2014, Comment 22). He also referred to A_r in the amount of substance scenario (Appendix 8, November 2013, Comment 4). Kirsty (Appendix 14, November 2011, Comment 2) referred to a preference to use a rhyme "*grams over rams*" rather than A_r as she understands less well what the symbol means. Neil (Appendix 9, June 2015, Comment 46) responded negatively to the symbolic language *delta negative*. These instances provide evidence to support avoidance of symbolic language in the eye tracker study (Chapter 5, Section 5.9, p. 175). Students are less familiar with symbolic language. At the end of Year 2 (August 2014) Kirsty referred to a water molecule as "*a hydrogen with two oxygen atoms stuck to each other*" (Appendix 13, Comment 22). This lapse, which was corrected when questioned, could have been caused by symbolic representation of a molecule of water as "H_2O".

6.4 Misunderstandings and misconceptions

This section analyses interview data for student misunderstandings and misconceptions relating to the scenarios. These misunderstandings and misconceptions are considered in relation to the extent they are affected by chemical language knowledge.

In his initial interview, Evan described a misconception that blowing on the coffee gave energy to the particles causing them to move towards the glasses. In November 2013 he stated:

"*when we blow the coffee you give the energy to the vapour, vapour water and the vapour water will be vibrate vibrate around and er, move quickly and it will be, and it will be quickly moved to your glasses*" (Appendix 7, November 2013, Comment 4).

This misconception is repeated in March 2014 (Comment 2), December 2014 (Comment 2) and June 2015 (Comment 2). In June 2015 Evan is specifically asked if blowing on the coffee gives the molecules kinetic energy and he confirmed that this was the case (Comments 3 and 4). This misconception was not addressed in the teaching activity and is not strongly influenced by chemical language.

Kirsty also demonstrated a misconception relating to blowing on the coffee. During the first two interviews, the scenario was given in the related forms of a kettle boiling (November 2011) and condensation appearing on a window after a cold night (April 2012) which do not involve blowing on liquid. On the third occasion (June 2013), the coffee cup scenario is used and Kirsty responded:

"*Right you've got a hot drink, you breathe on it. Cools down the molecules inside the hot drink causing the evaporation to a gas*". (Appendix 12, Comment 2)

Kirsty is confusing the cooling down of the body of liquid (coffee) at the macroscopic level with the process occurring at the sub-microscopic level. If *molecules* were cooling down they would be less likely to evaporate. She does not appear to understand the idea of process of evaporation taking heat energy away from the liquid. This misconception is influenced by the chemical language. The imprecise use of *molecules* influenced understanding at macroscopic and sub-microscopic levels.

At the sub-microscopic level, the greatest confusion was caused by *electronegativity*, *polarity* and the relevance of lone pairs of electrons on the oxygen atom. In March 2014, Ferne stated "*We've got a lone pair of electrons on the oxygen which makes it slightly electronegative*" (Appendix 1, Comment 16, Line 2). Misunderstanding *electronegative* makes this sentence problematic. The lone pair of electrons do not make the oxygen atom electronegative. *Negative* is a suitable word to use in this instance. Hence, misunderstanding the word affected the ability to produce a meaningful explanation. In December 2014, Ferne demonstrated better understanding of electronegativity (Comment 14, Line 5 and Comment 22) and she explained how polarity is produced using *dipole* appropriately. Ferne showed progression in her understanding and use of appropriate chemical language.

In the amount of substance scenario, Adam and Evan gave explanations relating to atomic radius rather than mass. In November 2012, Adam described the lead atoms as being bigger in terms of their number of electrons (Appendix 12, Comment 18) so lead atoms occupy more space than the sodium atoms (Comment 10). This is repeated in May 2013 (Comment 4), but when asked he recognised that the atoms had a greater mass (Comment 8). In March 2014, his understanding still appeared confused. He recognised that larger atoms have greater relative atomic mass (Comment 14) but still considered electrons to be the relevant part of the atom to explain the scenario (Comment 22). In November 2013 (Appendix 8, Comment 4) and May 2014 (Comment 2), Evan stated the relevance of relative atomic mass to explain the scenario. In June 2015 he correctly described dividing mass by molar mass (Comment 4) but then he states "*I think for the lead the atom is, the radius of atom is big and maybe they occupy more space. Therefore for the sodium, they occupy less space*". He now considered atomic radius as significant but in Comment 8 recognises that it is the size of the nucleus that produces greater molar mass.

This may occur because of confusion with density, volume and states of matter. When substances change state from solid to liquid to gas, particles are described as being further apart so the substance, therefore, has lower density than when solid. These students appear to consider that larger atoms will be further apart due to extra electron shells. Therefore, there are fewer atoms in a given mass. However, confusing mass and volume, implying the density of lead is lower than sodium.

In his initial interview, Neil considered density important when he stated "*In that case it would be due to the, how, condensed the particles or the atoms are within the substance. So in the lead the atoms would be further apart and there would be less of them than there are in 10g of sodium*" (Appendix 10, November 2012, Comment 2).

He states that lead atoms would be a larger size than sodium atoms (Comment 4) but not does indicate whether he is referring to mass, volume or radius. By the end of Year 0 he demonstrated progression in his understanding and recognised that gold atoms are heavier due to higher proton and neutron content (May 2013, Comments 2 to 4). In February 2014 he said atomic mass was an important concept (Comment 2) repeating this in June 2015. Therefore, Neil progressed from holding a misconception to correct understanding during Year 0 which remained throughout the study.

During Year 0, Ferne correctly explained the benzene scenario. By the end of Year 1 (Appendix 3, June 2015, Comment 2) she struggles to provide an explanation for the same scenario. When explaining phenol she stated:

"*instead of a hydrogen on each carbon kind of sticking out from the hexagon then we have a hydroxyl group which replaces the hydrogen and then that part has a different electronegativity? So that your electron cloud will be different. It bonds to the OH group. Is the more electronegativity, oxygen is more electronegative than hydrogen.*"

She thought delocalised electrons on the benzene ring interact with the oxygen atom, but her explanation is confused by imprecise use of electronegativity. She made two references to solubility of phenol in water being significant (Comment 2 and 14). The relationship between polarity in hydroxyl groups and solubility was significant in Year 1, so this is now her active concept. Linda showed a misconception in relation to phenol in May 2014 (end of Year 0) when she stated "*Because bromine is a stronger electrophile than the OH group itself and so it will take over its place and become neutral*" (Comment 26). She thought the bromine molecule substitutes the OH group and misunderstood *electrophile.* At the end of Year 1 (Appendix 6, May 2015) Linda stated:

"*it's an OH group which erm, it's more electronegative and it's gonna pull the electrons, it's gonna drag the electrons more er and hence it's being more reactive with the other species*." (Comment 4)

She focussed on polarity in the OH group rather than lone pairs of electrons interacting with the benzene ring. She misunderstood electronegativity. In Comment 8, Linda referred to the OH group pulling electrons in the ring to one side increasing reactivity. For Ferne and Linda, misunderstandings of *electronegativity* affected the quality of their explanations.

6.5 Interlanguage

This section analyses interview data for chemical interlanguage (Chapter 4, Section 4.11.2, p 130). Second language learning theory describes interlanguage as "*the language produced by the learner is a system in its own right, obeying its own rules, and it is a dynamic system, evolving over time*" (Mitchell, Myles and Marsden, 2013, p. 55; Chapter 2, Section 2.10.2, p. 75). Analysis of interview data indicates the existence of chemical interlanguage classified as *productive*, *unproductive* or *neutral*.

6.5.1 Productive chemical interlanguage

Productive chemical interlanguage (PCI) is transitional language usage that is not "expert" but may be helpful in developing appropriate conceptual understanding. Examples of PCI arise in relation to describing changes of state in the state of matter scenario. In April 2012 (Appendix 13), Kirsty used the sentence "*Energy gets taken away and it gets dropped down to a liquid*" (Comment 4, Line 5). This sentence includes two PCI examples. The phrase *energy gets taken away* refers to transfer of energy from gaseous water molecules to glass. Kirsty used personal chemical interlanguage conveying an understanding of energy transfer but does not use the expert vocabulary of *transfer*. The second occurrence of PCI is "*dropped down to a liquid*". Kirsty used personal chemical interlanguage to convey understanding of change in state from gas to a liquid. The phrase *it changes to a liquid* would have been appropriate but *dropped down* suggests interpretation of state change as a downward process perhaps in terms of energy change. In June 2015, Kirsty described molecules in a liquid "*as layers over each other transient moving*" (Comment 11). She created a unique utterance of *transient moving* for which a precise meaning is unclear, but this conveys a sense of molecules passing over each other. In May 2014 (Appendix 4) Linda referred to molecules in a liquid as "*a kind of varying motion driven state*". This is a unique utterance for which the precise meaning is unclear. It does, however, indicate that she had a sense of molecules flowing over each other.

Student explanations of *dipole* illustrate vocabulary used as students progressed from novice towards expert. Novice responses are characterised as only referring to *positive* and *negative ends* to a molecule with no distinction made between the strength of charge compared to a positive or negative ion. For example, Kirsty (Appendix 13, April 2012, Comment 20) stated "*there is polar ends so well negative positive*". Intermediate responses use a comparative qualifier such as *more* negative/positive or *a bit* negative/positive, progressing to *slightly* negative/positive. Expert responses refer to *partial charges* or *delta negative/positive* (Table 6.2).

Language level	**Novice**	**Intermediate**			**Expert**
Characteristic	no comparative qualifier	comparative qualifier			scientific language
Example	positive / negative	**more** positive / negative	**a bit** positive / negative	**slightly** positive / negative	partial charges delta positive / negative

Table 6.2 Chemical interlanguage progression describing polar molecules

Table 6.3 shows the usage of these words by five students who tried to explain bond polarity (Adam did not provide an explanation). Only Evan used the expert language of *delta negative*. Neil regressed in his language usage from *more negative/positive* in May 2013 to no qualifier in June 2015. This suggests his chemical interlanguage regressed as these were no longer active words in his learning. Linda interchanged between no qualifiers and using *more negative/positive* within the same interviews, showing inconsistency.

Vocabulary / Student	negative / positive	more	a bit	slightly	partial / delta
Kirsty	August 2014				
Neil	June 2015	May 2013			
Linda	May 2014 June 2015	February 2014 May 2014 June 2015			
Ferne				March 2014	May 2014
Evan	March 2014		March 2014		December 2014

Table 6.3 Occurrence of student utterances describing bond polarity

In the Benzene scenario, Linda stated "*The OH group itself is sort of slightly destabilising the molecule*" (Appendix 6, May 2014, Comment 8). The use of *destabilising* is an example of PCI. Linda thought electrons from the oxygen atom interact with the benzene ring, decreasing stability and increasing reactivity of the molecule. Linda used *pulling power* instead of *electronegativity* in May 2014 (Appendix 4, Comment 26, Line 4) when she stated:

"*because oxygen is a larger molecule it's got greater pulling power than the hydrogen so which leaves the hydrogen exposed hence its positive side*".

This statement is an example of PCI because, although the language is not expert (*molecule* is used instead of *atom* and the reference to *hydrogen exposed*) it does convey appropriate understanding. Ferne also used *pulling power* in conjunction with *electronegative* in December 2014 when she stated:

"*The electron cloud spends more time around the oxygen and attracts the hydrogen towards the oxygen because the oxygen is more electronegative and has more pulling power*".

She is using the informal phrase to confirm her understanding of *electronegative*.

6.5.2 Unproductive Chemical Interlanguage

Interview data provide evidence of chemical interlanguage that can lead to or reinforce misconceptions and misunderstandings. This is called Unproductive Chemical Interlanguage (UCI). For example, when discussing the arrangement of molecules in a liquid, Neil described intermolecular forces as "*staples it together to form a liquid*" (Appendix 9, February 2014, Comment 8). *Staples* suggests a rigid or fixed nature to interactions between the water molecules contrasting with PCI examples in section 6.5.1 that suggest a fluid arrangement.

UCI occurred when one key word is misunderstood. Kirsty, in April 2012 (Appendix 13, Comment 14) for example, explained attraction between water molecules as

"*it's the hydrogen bonding between them in the molecules so the attraction between oxygen and the hydrogen of separate because the oxygen is more electronegative and it* *will slightly attract hydrogens from a different molecule, erm and then as it goes to liquid I don't know, less energy. I am not sure*".

The key word is *electronegative*, which is incorrectly used. *Negative* would have been appropriate. The comment loses meaning, so Kirsty lost confidence in her response after this error, becoming unable to develop the explanation further. Poor understanding of electronegativity is evident in May 2014 when Linda was explaining the Benzene scenario. She states:

"*Different molecules and different, er, atoms have different electronegativity. So if it needs to be above a certain level or below a certain level so if its bromine is more electronegative so it is more likely to react than if it's something less electronegative*".

The first sentence is a general statement and is understandable but the second sentence is confused. In June 2015, usage of *electronegative* by Linda results in another example of UCI. When discussing reactivity of phenol she stated:

"*it's an OH group which erm, it's more electronegative and it's gonna (going to) pull the electrons, it's gonna drag the electrons more er and hence it's being more reactive with the other species*" (Appendix 6, Comment 4).

6.5.3 Neutral Chemical Interlanguage

There were instances of language usage that do not significantly impact on understanding. These are Neutral Chemical Interlanguage (NCI). Adam (Appendix 11, May 2013, Comment 2) referred to *gas form* and Kirsty referred *to gas form* and *liquid form* (Appendix 13, June 2015, Comment 4). The word *form* could be omitted and simply referred to as *gas* or *liquid*, or expert language would refer to the gas or liquid *phase*. Evan used *phase* in December 2014 (Appendix 7, Comment 6). The use of *form* does not convey further understanding or reinforce misunderstanding. Another example of NCI is the omission of *atom* or *molecule* when discussing size of atoms in the amount of substance scenario. Kirsty for example, stated:

"*one gram of hydrogen is one mole, is in one mole, that's it. The same number of molecules so it's one, yeah one mole of hydrogen is in one gram of hydrogen.*" (Appendix 14, April 2012, Comment 18).

Lack of reference to *hydrogen atoms* and ambiguous reference *to molecules* makes her sentence unclear. However, Kirsty has understanding that a certain mass of hydrogen equates to one mole. To progress to expert language the correct use of *atoms* or *molecules* is required. A further example of NCI is the omission of *relative* from *relative atomic mass*. In November 2013, Linda stated "*for sodium its atomic mass lighter*". She does not use the complete phrase of *relative atomic mass* but this omission does not detract from the meaning. Further examples of this omission were demonstrated by Ferne (Appendix 2, December 2014, Comment 16) and Evan (Appendix 8, June 2015, Comment 4).

Another example of NCI is use of appropriate comparators such as *larger, smaller, greater* and *fewer*. Evan showed examples of self-correcting comparator choices but not necessarily for an expert alternative. For example, in the amount of substance scenario, Evan stated "*Because the relative atom mass for the sodium is hi, is bigger than that of the lead*" (Appendix 8, Comment 2). In this example he appeared about to say *higher* but replaces this with the unscientific *bigger*. At Comment 4 he corrected himself twice when he said "*the mole of the sodium is larger is bigger is more, is more than that of the lead*". In this example he chooses *more,* which is the most appropriate word. Kirsty used the comparator *stronger* rather than *higher* when talking about electronegativity in August 2014 (Comment 30) when she stated "*the electronegativity for oxygen is stronger than the hydrogen electronegativity*". In the state of matter scenario, Linda (Appendix 4, June 2015) stated "*The bigger molecules they have more pulling power than the lower molecules*". *Larger* would have been more appropriate than *bigger* and *smaller* rather than *lower*.

In some instances, however, the comparator may be regarded as UCI. Linda for example, in the amount of substance scenario (Appendix 4) stated "*Hence for sodium its atomic mass lighter, one's heavier than the other*." *Lighter* and *heavier* are used rather than *greater* and *less* because of the reference to *weight* in the previous sentence. The inappropriate comparator reinforces the conflation of *relative atomic mass* and *weight.*

6.5.4 Formulaic phrases and backsliding

There is evidence students adopted systematic phrases. Ferne referred to "*activate the ring*" (Appendix 3, May 2014, Comment 9, Line 3) when explaining reactivity of phenol but her understanding of the phrase appeared unclear. Linda used the phrase "*thermodynamically favourable over thermodynamically unfavourable"* (Appendix 4, May 2014, Comment 4, Line 8) but was unable to elaborate on the explanation. These examples suggest that sometimes students use formulaic phrases but have limited understanding of their meaning.

In November 2012, Neil referred to particles "*not moving quite as fast*" (Appendix 9, Comment 4) and in May 2013 referred to particles "*moving randomly*" (Comment 8). In June 2015 (Comment 4), Neil describes the molecules in the coffee as "*less active when they are cooling down or more active when they are heating up*" rather than referring to molecular movement or vibration. This indicates that Neil's chemical language had backslid to a less appropriate form than one he used previously.

6.6 Language based learning strategies

This section considers evidence for language based learning strategies used by the interview students. Teaching strategies in Year 0 emphasised the value of understanding origins of scientific words and affixes (Chapter 3, Section 3.3.2, p. 91) while understanding affixes was tested in the CLDT (Chapter 4, Section 4.8.3, p. 111). Ferne demonstrated conscious use of this language skill, emphasising *inter* in *intermolecular forces* (Appendix 1, May 2014, Comment 4, Line 3) and *ene* in *hexene* (Appendix 3, June 2015, Comment 28). This indicates that this remained an active strategy for Ferne after Year 0.

Neil reported that he found the linguistic strategies useful, making the following comment:

"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!"

Linda made good use of personal glossaries during Year 0, made notes of key words in class and appreciated the interactive nature of the classes. She commented:

"*Language is one of those things you learn passively, you can't measure it exactly. You learn a language by listening, talking, writing. There have been opportunities in the class, talking to other students and the ability to be involved in the teaching. It helps a lot if you get something wrong and I am less embarrassed and self-aware*."

This suggests that development of a social constructivist based learning environment had a positive effect on Linda's learning experience.

She found the FOCUS tool useful, commenting:

"Very useful especially if you are foreign; it makes the phrases available. My problem is repeating the same word for example and / therefore. It brings fluency to the language."

In Year 1, however, she found it difficult to use these strategies due to time constraints.

6.7 Language conditions for success

Chapter five indicates that there is a correlation between student chemistry test scores and CLDT scores (Section 5.6, p. 166). Furthermore, students who scored below 40% in the October CLDT were more likely to fail than students who scored greater than 40% (Section 5.7, p. 171). By the end of the study, Kirsty successfully completed her degree in Biomedical science obtaining a 2:1, Ferne, Linda, Neil and Evan were continuing with their studies and Adam had withdrawn.

This section uses Spolsky's model of second language learning (Spolsky, 1989; Chapter 2, Section 2.10.1, p. 69) to compare outcomes for interview students Evan and Adam. It provides a speculative explanation for the differing outcomes of these two students. This model states that student attitudes inform motivation which ultimately affects outcomes. Data was not collected for these students in relation to attitude and motivation so evidence cannot be provided to substantiate that this is the underlying cause of the different outcomes in this instance.

Evan and Adam originated from China and were studying chemistry so are comparable in terms of linguistic background and subject choice. They both had the same opportunities for learning chemical language. Therefore, according to Spolsky's general model (Spolsky, 1989; Figure 2.9, p. 55), their ability to make use of these opportunities was influenced by the central factors of age, personality, capabilities and previous knowledge. Evan and Adam were of a similar age and presented with similar qualifications at the start of Year 0. Personality and capabilities were not specifically assessed but significantly, Evan and Adam's learning outcomes were markedly different. Evan may have been a more capable learner than Adam, adopting better learning strategies.

These central factors are influenced by motivation. Motivation was not quantifiably assessed in this study but Evan appeared more motivated than Adam. Evan had excellent attendance, arriving early for lectures. He would look at class presentations prior to lectures to familiarise himself with terminology and sought clarification of content. Adam had periods of absence and did not demonstrate positive study strategies in the way Evan did. Condition 53 of Spolsky's model states that "*a learner's attitudes affect the development of motivation*" Spolsky (1989, p. 150). He states that although attitudes do not directly influence learning, they lead to motivation which does. This statement is based on studies such as Gardner (1985), who demonstrated that attitude measures may account for a significant amount of variability in second language learning outcomes. In the context of second language learning, he states that two significant attitudes: attitudes to people who speak the target language and attitudes to practical use to which the learner assumes he or she can put the language being learned. According to Spolsky (1989) motivation is influenced by learners' attitudes towards the community speaking the target language and towards the learning situation. People speaking the target language expertly are the chemistry community and the practical use may relate to potential careers. Evan may have had a more positive attitude towards the chemistry community to which he was progressing to and had defined personal career goals. Attitudes are, in turn, influenced by social contexts. Spolsky (1989) argues that language is primarily a social mechanism and language is learned in social contexts. Condition 42 states that "*the number of people who speak a language as a first or second language influences the desire of others to learn it*" (Spolsky, 1989, p. 133). The number of people speaking chemical language is, in theory, the same for Evan and Adam. However, Evan appeared to have a strong desire to learn to speak chemical language (attitude) which then impacted his motivation. Spolsky (1989, p. 136) argues that social and political status of a language is important in influencing learners' attitudes. It is possible that Evan was operating within a social context that gave greater status to chemical language and the chemistry community than was the case for Adam. This relates to the Linguistic Convergence condition (Condition 48, Spolsky 1989, p. 142) which states that language acquisition is likely when there is a desire for social approval and a strong value is placed in being able to communicate with its speakers. It is possible that Evan had a strong desire for social approval and placed value on being able to communicate within the chemistry community. Condition 44 states that "*informal learning situations are only possible with languages with vitality*" (Spolsky, 1989, p. 135). Vitality refers to a population that actively uses a language rather than a classical language such as Latin in which the opportunities for informal usage would be very limited. Opportunities for informal usage for Evan and Adam would have been limited. The study did not record the extent to which they engaged with opportunities outside the classroom to be exposed to and practise chemical language.

6.8 Summary

This chapter analysed longitudinal student interview data gathered in response to scientific scenarios. It reports developments in chemical language usage over time with particular emphasis on the sub-microscopic level. Misunderstandings and misconceptions were discussed. Data were analysed for chemical interlanguage. Evidence for continued use of language based learning strategies was presented and a comparison of a successful and unsuccessful student was also undertaken from a language acquisition perspective. The next chapter discusses the findings in relation to the research questions and implications for teaching practice.

Chapter 7

Discussion

This chapter provides responses to the research questions and associated hypotheses, implications for chemistry teaching practice, a discussion of the limitations and potential for future research. The study aimed to explore the role of language of science in the learning of chemistry for non-traditional students. The impact of a range of unique language based activities including corpus linguistics within chemistry teaching on students chemical language was investigated. To monitor this, a novel chemical language diagnostic test (CLDT) (Chapter 4, Section 4.8, p. 105) was developed, an eye tracker investigation (Chapter 4, Section 4.10, 118) and student semi-structured interviews (Chapter 4, Section 4.11, p. 126) were undertaken. This discussion considers the main findings of the study in relation to the four research questions.

7.1 RQ1 - Does chemical language comprehension ability affect potential undergraduates' outcomes and success?

The CLDT has made it possible to assess students' understanding of aspects of chemical language throughout Year 0. This is the first time that the efficacy of a specific chemical language test on students' learning has been demonstrated. Previous studies such as Pyburn et al. (2013) relied upon demonstrating correlations between general language comprehension assessments and achievement in chemistry (Chapter 2, Section 2.5, p. 55).

CLDT results support the hypothesis that students with weaker chemical language comprehension skills are less likely to be successful. Students who scored above 40% in the October CLDT were more likely to be successful than students who scored below 40%. Figure 5.17 (p. 158) shows a moderately strong correlation ($r = 0.53$) between October CLDT score and May chemistry examination score indicating that October CLDT score is a predictor of final examination score. Thirty two out of thirty five (91%) students who scored over 40% in the October CLDT passed the May examination compared to ten out of seventeen (59%) of students who scored below 40% in the October CLDT. This result supports significance of the division of the cohort into Red (below 40%) and Green (equal to and above 40%) sub-groups. Red sub-group students had an increased chance of failing the course compared to Green sub-group students. However, ten out of seventeen of the Red sub-group students passed the May exam with five students scoring 50 – 60% and five students scoring over 70%. Therefore the CLDT has revealed differences in responses by Red sub-group students. Five students performed as well as students who had higher October CLDT scores, demonstrating significant learning gains during Year 0.

This outcome is supported by data in Tables 5.16 and 5.17 (p. 167 - 168) which tracks individual CLDT results for Red sub-group students across Year 0. In October, thirty one students (36%) scored below 40% and by the end of the study, fourteen red sub-group students were still continuing with their studies at the end of Year 1 (AY2) or Year 0 (AY3). Thirteen out of fourteen of these students were individuals that had improved their CLDT scores over the course of Year 0. The one remaining student had scored below 40% in October and continued to do so in December. Three possible explanations are suggested for these observations.

7.1.1 Difficulty in moving between the macroscopic and sub-microscopic levels

Johnstone's triplet (Johnstone, 1991) identifies that chemistry is difficult for students as they are required to oscillate between macroscopic, sub-microscopic and symbolic levels (Chapter 2, Section 2.2.1, p. 34). This has been refined recently by Taber (2013), who proposes the symbolic level acts as conduit between macroscopic and sub-microscopic levels. Therefore, limited chemical vocabulary and language skills restrict students' ability to operate at macroscopic and sub-microscopic levels as well as bridging the two. Evidence to support this is provided by the interview and eye tracker data.   All interview students demonstrated difficulties operating within and between the macroscopic and sub-microscopic levels (Chapter 6, Section 6.1, p. 185). Eye tracker data indicated Red sub-group students had greater difficulty interpreting text that transitioned repeatedly between the macroscopic and sub-microscopic levels (Chapter 5, Section 5.9, p. 175).

7.1.2 Variability in response to the teaching activities

Within the Red sub-group variability occurred in response to the teaching strategies as measured by the May exam results (Figure 5.17, p. 164). Seven students did not respond to the teaching activities and did not pass the May chemistry exam. Five students responded sufficiently to pass the exam in the 50 – 60% range, while a further five students responded strongly to the teaching activities and passed the May exam with scores higher than 70%. Interview data indicates possible reasons for this variability. Adam and Evan, for example, were international chemistry students with similar backgrounds but demonstrated very different outcomes. Evan was highly motivated and made significant progress in his CLDT score during year 0 (Appendix 15). He successfully passed Year 1 and continued with his studies. In contrast, Adam appeared less motivated and, whilst he managed to pass Year 0, he was unsuccessful in Year 1. Section 6.7 (p. 210) discussed how Spolsky's model of language learning indicates that differences in motivation are determined by students' attitudes. These are, in turn, influenced by the social contexts that the student operates in.

7.1.3 Information processing

Johnstone and Selepeng (2001) applied the information processing model (Chapter 2, Section 2.4, p. 52) in relation to students struggling to learn science in a second language. They suggest these students have reduced capacity in the working space in the brain because this is occupied by translating and processing language. Therefore, less information reaches long term memory. This model may explain why students who continued to score poorly in the CLDT, demonstrating weaker chemical language knowledge were less likely to be successful in Year 0. These students use more working space capacity processing language so are less able to develop their subject knowledge and understanding. The eye tracker study indicates that Red sub-group students demonstrated a less focussed reading strategy than Green sub-group students (Chapter 5, Section 5.9, p. 175). This suggests they found the text challenging to comprehend and experienced difficulty identifying significant words and processing sections of text. This has significant implications for their ability to access and interpret chemistry materials quickly and meaningfully. Furthermore, these students struggle to keep up with and follow the lecture content of the lectures because they lack linguistic fluency. This may result in disengagement and decreased motivation, perhaps as Adam experienced.

7.2 RQ2: In what ways do potential undergraduates' understanding of chemical language develop during a one year, full-time foundation programme?

Within this section I discuss evidence for particular linguistic challenges evident in data collected. Section 7.2.1 considers results obtained from the CLDT and section 7.2.2

reflects on explanations obtained in student interviews. The results support the hypothesis that some categories of chemical language are more challenging for students than others. Understanding of non-technical words improved during Year 0 with repeated exposure.

7.2.1 Developments in CLDT scores during Year 0

Previous studies such as Cassels and Johnstone (1985) highlighted difficulties with particular areas of scientific language. Development of the online CLDT enables data to be collected on student understanding of different areas of chemical language and items within these. Chapter 5 discussed the CLDT results and findings are summarised here.

All Year 0 students show weakness in lexical-based word categories at the start of the course and this remains the case at the end of year 0. Figure 5.2 (p. 141) shows that the lowest scores in the CLDT in October were recorded in *acid words, kinetic words* and *word choice* sections for all students in AY23 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. No previous study has explored the extent of lexical awareness amongst science students.

Cassels and Johnstone (1985) highlight difficulties associated with non-technical language. In this study, understanding of non-technical language improved during Year 0. Figure 5.2 (p. 125) shows that the October CLDT score for this section was low with an average of 42% for the Red sub-group. The words *solution, reduction* and *weak* register very low scores (Figure 5.4 p. 146). However, during Year 0, 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* registered high scores of 80 and

93% respectively. *Weak* and *reduction* receive explicit and repeated use in different contexts during Year 0, 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 performed very poorly, indicated by the high standard deviation of 33.9 (Table 5.3, p. 141). Limited understanding of these fundamental and ubiquitous words is a concern so their meaning was addressed explicitly early in Year 0 (Chapter 3, Section 3.3, p. 85). 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 at the end of year 0. Interview students Evan, Adam, Linda and Kirsty interchangeably used words such as *atom* and *molecule* (Chapter 6, Section 6.3.2, p. 199). This is an example of loose language (Cassels and Johnstone, 1985; Chapter 2, Section 2.4, p. 47) possibly due to limited understanding of differences between these words and/or a lack of careful consideration of correct word choice.

Symbolic language are problematic for Red sub-group students. This sub-group recorded a low score in the symbolic language section at the start of Year 0. The section remained problematic for some students at the end of Year 0 (Figure 5.7, p. 153). In particular, nearly 50% of Red sub-group students did not consider H_2O and OH_2 to be equivalent at the end of Year 0. 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. Symbolic language was rarely used in student interviews and one interview with Neil featured references to dislike of symbolic language (Chapter 6, Section 6.3.5, p. 202). Evidence from the eye tracker study indicates that students tended to avoid symbolic language.

7.2.2 Developments in scientific explanations during year 0

Section 6.1 (Chapter 6, p. 185) discussed responses to scientific scenarios by interview students. The states of matter scenario provided an opportunity for an explanation to progress from macroscopic (*liquids, gases, heat, evaporation etc*) to a sub-microscopic explanation (*molecules, kinetic energy, intermolecular forces, hydrogen bonding etc*). All interview students provided explanations early in Year 0 that tended to focus on macroscopic rather than sub-microscopic language. This is unsurprising given that students had just started the course so would be unlikely to be aware of the relevant sub-microscopic vocabulary. Their second explanations showed varying levels of success in incorporating and utilising new sub-microscopic vocabulary. Ferne, Linda and Kirsty demonstrate substantive effort in applying relevant sub-microscopic vocabulary, illustrated by high CCL scores. They recorded high values of ICL indicating they were trying to utilise this vocabulary, albeit incorrectly. Instances of ICL related to confused use of *electronegative*, indicating students exhibiting transitionary state or interlanguage (Selinker, 1972). These explanations illustrate the challenges of engaging in social constructivist learning as the students attempted to apply new learning and words to their explanations. Evan and Neil extended their explanation to sub-microscopic level but did not explore ideas relating to electronegativity. Consequently, their CCL and ICL scores are lower than those of Ferne, Linda and Kirsty. Adam provided limited explanations overall and displays very limited ability to articulate ideas relating to intermolecular forces. He made little progress in transitioning from macroscopic to sub-microscopic.

The amount of substance scenario (Chapter 6, Section 6.1.2, p. 189) contains a macroscopic (a mass of a substance) to sub-microscopic (more/less atoms) transition within the initial question. A suitable explanation requires transitions between these two levels relating size (in terms of relative atomic mass) of an atom of an element to the total number in a given macroscopic mass. By the end of Year 0, no interview students could provide a coherent explanation that utilised macroscopic (*moles, mass in grams*) vocabulary and sub-microscopic (*relative atomic mass, protons, neutrons*) successfully. Ferne, Linda and Kirsty showed improved usage of chemical language such as *moles* and *molar mass*. Adam and Neil showed limited progress. Five interview students referred to *relative molecular mass* rather than *relative atomic mass*, resulting in discussions about differences between *atoms* and *molecules*. The confusing nature of macroscopic and sub-microscopic vocabulary interplay in this scenario made it impossible for students to present a clear and coherent explanation. Linda and Adam regarded the size of the atom in terms of the space occupied (i.e. atomic radius rather than mass) as the relevant concept.

The benzene scenario, added later, was attempted by Ferne and Linda. This scenario requires a significant amount of unfamiliar sub-microscopic level vocabulary *e.g. electron density, electrophile, pi bonds, delocalised electrons, polarity and dipoles*. Both students, during Year 0, demonstrated an ability to try to use relevant terminology to provide a coherent explanation. The success of this was variable, as some terminology was applied correctly and some not. The students were at a chemical language transitionary phase, demonstrating aspects of interlanguage (Chapter 6, Section 6.5, p. 206).

7.3 RQ 3: In what ways can teaching strategies utilising linguistic strategies such as corpus linguistics be applied to science education to enhance student understanding of scientific language?

Pyburn et al. (2013) argued that language comprehension skills should be incorporated within chemistry courses. This study demonstrates how a broad range of language focused strategies including the development of FOCUS can be successfully incorporated into main chemistry course content. Large effect sizes (Table 5.10 p. 152) suggest the teaching strategies had a significant effect on both student sub-groups. However, individual section scores remained significantly different between Green and Red sub-groups for five out of the seven sections at the end of Year 0 indicating that the Red sub-group had still not developed to Green sub-group standards. Largest effect sizes were recorded after the first term, accounted for by the CLDT emphasising content taught in the first term. These results support, but cannot confirm, the hypothesis that language focused teaching activities can improve achievement in this context.

Corpus linguistics was employed throughout the chemistry course. Firstly it was used to provide multiple examples of word use in context *e.g. strong, weak* (Chapter 3, Section 3.3.10 p. 97). This is useful with vocabulary that has variable meanings in different contexts. Secondly, corpus linguistics was used to develop understanding of scientific affixes and word roots. This develops student interpretive skills and their ability to decode new and unfamiliar language. Thirdly, FOCUS was used to expand lexical knowledge by exploring connections between words and uses across disciplines. This is useful with students progressing to disciplines in which word usage may be different. Lastly, it was used to refine appropriate use of scientific words *e.g. produced, released* (Chapter 3, Section 3.3.9, p. 96).

FOCUS was a useful tool enabling exploration of meanings and usage (Chapter 6, Section 6.6, p. 211). Ferne, in particular, engaged with the principles behind language-focused strategies, regularly applying these to her learning. She developed analogies for chemical structures, demonstrated decoding strategies and used rhymes and associations to help remember important terminology.

7.4 RQ 4: How do potential undergraduates' chemical language usage and learning strategies develop with progression to the undergraduate programme?

Section 7.1.1 considered scientific explanations provided by students in relation to transitioning between macroscopic and sub-microscopic levels. In this section I consider how responses to scientific scenarios developed as students progressed through their undergraduate programmes.

When a scenario remained relevant to the student's degree programme, evidence of incorporation of new terminology and concepts occurred. For example, in the states of matter scenario, all three biological/biomedical students (Ferne, Linda and Kirsty) extended their explanations with thermodynamic ideas relating to entropy (Chapter 6, Section 6.2.1, p. 192). Ferne and Linda also used new terminology to which they had been introduced in Year 1 that were equivalent to terms used in Year 0, *e.g. atomic weight (relative atomic mass), gram molecular weight* (*molar mass*). Evan demonstrated extensions to his vocabulary by incorporating references to *phases* and *electrocentre* into his explanations.

When a scenario was less relevant to a student's degree programme evidence of diminished use of relevant vocabulary is apparent. Neil for example, struggled to recall relevant vocabulary relating to water molecules in the states of matter scenario. The benzene scenario showed Ferne and Linda as unable to recall relevant vocabulary at the end of Year 1. Kirsty also demonstrated difficulties in this area as she progressed further through her degree programme, such that by Year 2 she could not recall relevant vocabulary (Chapter 6, Section 6.2.1, p. 192). Concepts such as *hydrogen bonding* were relevant to her course but her ability to explain these had faded. Ferne's Year 1 interview demonstrated some improvement in her explanation of the states of matter scenario. Generally, however, students did not show improved use of relevant terminology as they progressed through their degree programme.

There was evidence of resilience of colloquial phrases such as *pulling power* in relation to *electronegativity*. Ferne and Linda repeated this phrasal verb in interviews in Year 1 (Chapter 6, Section 6.5.1, p. 206).

The student interviews show multiple instances of terms being confused. *Electronegative* was confused with *electron density* (Ferne, Chapter 6, Section 6.1.3, p. 191), and *negative* (Kirsty, Chapter 6, Section 6.5.2, p. 208), i*nteract* with *react* (Kirsty, Chapter 6, Section 6.1.3 p. 191). Linda confused *dislocated* with *delocalised* (Chapter 6, Section 6.2.3, p. 194). *Mole, molar mass, relative atomic mass, relative molecular mass* were confused by Ferne, Linda and Evan (Chapter 6, Section 6.1.2, p. 189, and Section 6.2.2, p. 194). Further examples were *alkene* with *alkali* (Linda Chapter 6, Section 6.3.3, p. 200). *convection* with *convention* (Evan, Appendix 7, June 2015, Comment 8) *nucleus* with *neutron* (Evan, Appendix 8, June 2015, Comment 8) and *proton* with *positron* (Chapter 6, Section 6.2.2, p. 194). The significance of this is discussed in Section 7.5.

Interviews revealed uncertain use of comparator terms such as *higher, bigger and slower* (Chapter 6, Section 6.5.3, p. 209). Ferne, for example, was unsure of the use of *lower*, *less* and *fewer* and Linda confused *higher, lower*, *faster, slower, lower and smaller*. Evan shows confusion of *higher, bigger, larger* and *more*. Kirsty was unsure of appropriate use of *stronger* and *higher*. These may be regarded as examples of neutral chemical interlanguage (Section 6.5.3, p. 209).

7.4.1 Application of learning strategies

The data partially supports the hypothesis that language focused skills developed in Year 0 continue to be utilised. Ferne demonstrated continued application of scientific affixes and Neil stated that he had found the linguistics strategies particularly useful after Year 0 (Chapter 6, Section 6.6, p. 211). Linda demonstrated good use of personal glossaries in Year 0 but did not continue with this in Year 1 due to time constraints. There was also no evidence of continued application of corpus linguistics beyond Year 0. This is unsurprising without active engagement and application in the teaching.

7.5 Linguistic demand in multiple dimensions

In this section, I discuss how scientific words present challenges to non-traditional students in a variety of dimensions. I propose a speculative model for assessing linguistic demand of chemical vocabulary to explain data from the study. The evidence is provided by CLDT data (Chapter 5, p. 133), interview data (Chapter 6, p. 180) and eye tracker data (Chapter 5, Section 5.9, p. 175)

Previous studies indicate students' difficulties with scientific words relating to non-technical and dual meaning vocabulary (*e.g.* Cassels and Johnstone, 1985; Song and Carheden, 2014). Authors have attempted to classify scientific vocabulary in terms of the roles they play in language (*e.g.* Wellington and Osborne, 2001). This study adds further dimensions to our understanding of the challenges faced by chemistry students when developing meanings for chemical language. Any specific word may be considered as operating in four dimensions of linguistic demand.

The first dimension is **non-literal meaning**. This is the extent to which meaning can be determined directly from the word itself. It encompasses ideas of Sutton (1992, 1998) that consider scientific words as interpretive tools rather than labels alone (Chapter 2, Section 2.6, p. 56). For example, *capillary* in the context of *capillary attraction* (Box 1, p. 28), presents high linguistic demand in this dimension because the meaning is not immediately apparent from the word. The meaning cannot be determined by association with words such as *blood capillary*; neither can its meaning be immediately determined from its Latin root (*of hairs*) without knowledge of the scientific story and capillary tubes. In contrast, *gas* would score low in this dimension because of familiarity in an everyday sense (*e.g.* "*I need some gas for the stove*") and similar meaning in chemistry (*e.g.* "*the reaction produced a gas*"). Therefore, *gas* is likely to be understood correctly in a chemistry context. Thus the non-literal demand for *gas* is lower than for *capillary*. Other phrases that may score high in this dimension include *Le Chatelier's principle*, *Markovnikov's rule* and *the Aufbau principle* because no indication of the process to which these refer is apparent (knowing the German meaning of *Aufbau* would reduce the non-literal demand of the Aufbau principle). Dual meaning vocabulary also scores high in the non-literal dimension. For example, the word *weak* in the context of *weak acid* scores high in this dimension because its meaning in this context as an acid that partially dissociates is different to its everyday meaning (see

Figure 7.6). In the context of *weak intermolecular forces*, however, *weak* would score lower because the meaning is synonymous with an everyday context of something lacking strength and being easy to break. Interview data provided evidence of difficulties with words with non-literal meaning such as electronegativity (Chapter 6, Section 6.1.1, p. 185). CLDT data shows how Red sub-group students, in particular, found non-technical words with dual meaning challenging at the start of Year 0 (Chapter 5, Section 5.4, p. 143).

The second dimension is **sub-microscopic**. Interview data show that these students found it difficult to articulate explanations in the sub-microscopic domain (Section 7.1.1, p. 216). This is because the concepts are abstract, difficult to visualise and require use of sub-microscopic vocabulary they did not possess. *Electronegativity,* for example, presented significant challenges because explaining and understanding this is sub-microscopic. *Electronegativity,* therefore, has high linguistic demand in this dimension. *Gas,* in contrast, operates at the macroscopic level so presents lower linguistic demand. The modification of *gas* to *gas molecules* transfers the term to the sub-microscopic level, increasing the linguistic demand in this dimension. Symbolic language is included within this dimension as this often refers to sub-microscopic entities. Macroscopic and sub-microscopic ambiguity of meaning is also associated with symbolic language.

The third dimension is **similarity** to other words. Interview data produced examples of students using similar sounding words with different meanings (Section 7.4, p. 222). If a word can be easily confused, this corresponds to greater linguistic demand in this dimension. For example, *electronegative* was confused with *negative* and *electron density* and, therefore, has a high linguistic demand. *Gas*, however, is less likely to be confused with similar sounding words so has a low linguistic demand in this dimension.

The final dimension is **multiple contexts**. Linguistic demand is increased when the same word can be used in multiple contexts with different meanings, for example, *strong* can be used in multiple contexts of *strong metals, strong intermolecular forces or strong acids*. The contexts generate different meanings, so linguistic demand is increased. *Gas*, however, has similar meanings in different contexts *e.g. the gas was contained under high pressure; the syringe filled up with a gas; propane gas has a low boiling point*. Therefore, the linguistic demand is low for *gas* in this dimension. CLDT data for Red sub-group students indicates difficulties understanding words with multiple meanings (Chapter 5, Section 5.5, p. 153)

7.5.1 Graphical representation of linguistic demand

I propose a mechanism to visualise the impact of these dimensions. A chemical language word may be scored between 1 to 10, where 1 represents low linguistic demand and 10 is high. A score is generated in all four dimensions for any given word, as shown in Table 7.1 for *electronegative*.

Linguistic dimension	Score	Explanation
Non-literal meaning	5	The first part of the term indicates the involvement of electrons but the second part does not provide further explanation of the meaning *i.e.* the ability of an atom to attract the pair of electrons in a covalent bond.
Sub-microscopic	10	Operates exclusively in the sub-microscopic domain.
Similarity	10	May be confused with similar terms such as *electron density* or *negative*.
Multiple contexts	1	The term is not used in different contexts with different meanings.

Table 7.1 Linguistic demand for *electronegative* in four dimensions

These scores can then be visualised graphically as in Figure 7.1.

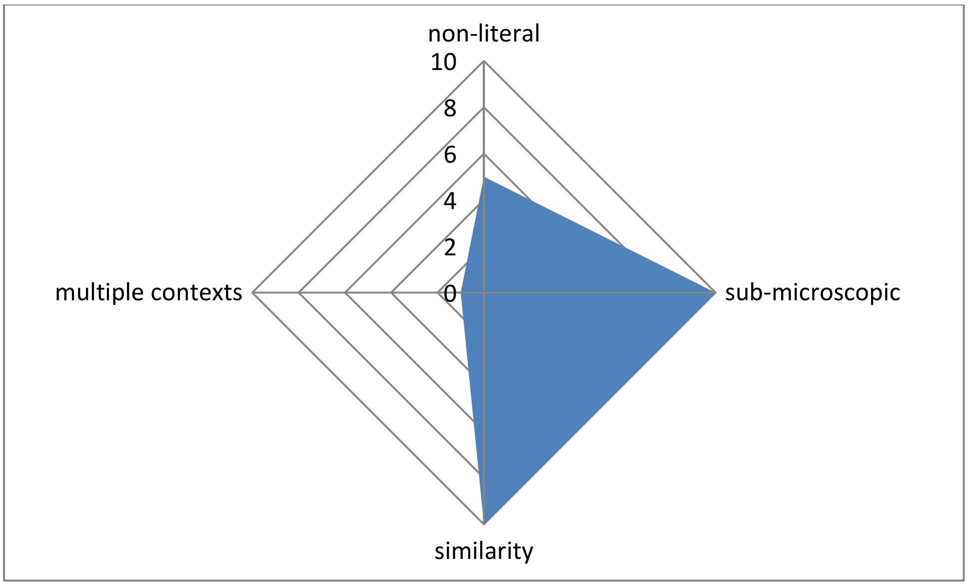


Figure 7.1 Linguistic demand for e*lectronegative* in four dimensions

Electronegative exhibits high linguistic demand in the sub-microscopic and **s**imilarity dimensions. Compare this with the similar word *electrophile* (Figure 7.2), which also exhibits high linguistic demand in the sub-microscopic and similarity dimensions. The non-literal dimension is given a lower score for *electrophile* than *electronegative.* Meaning of *electrophile* can be determined assuming knowledge of the suffix "*phile*" *i.e*. *electrophile – electron loving*. Although e*lectron loving* is different to a dictionary or examination definition of an electrophile as "an electron pair acceptor", it does indicate correct meaning.

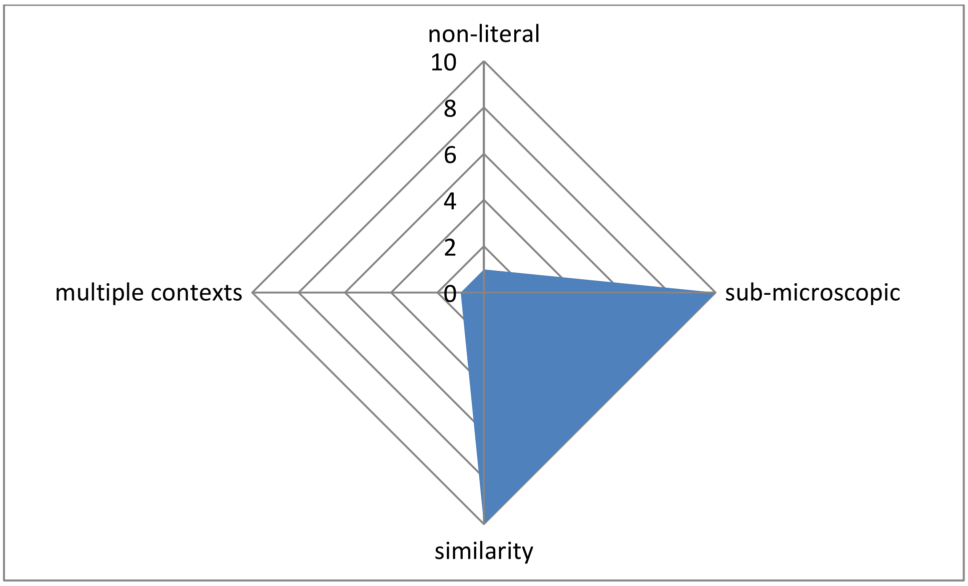


Figure 7.2 Linguistic demand for *electrophile* in four dimensions

In comparison, *gas* scores low in all four dimensions (Table 7.2). The linguistic demand graph now defines a much smaller overall area (Figure 7.3).

Linguistic domain	Score	Explanation
Non-literal meaning	1	The term readily associated in everyday language and Greek origins enhance meaning.
Sub-microscopic	2	Operates in the macroscopic level except when collocated with molecules.
Multiple contexts	1	The term means similar things in different contexts.
Similarity	1	There are no terms that it can be readily confused with.

Table 7.2 Linguistic demand for *gas* in four dimensions

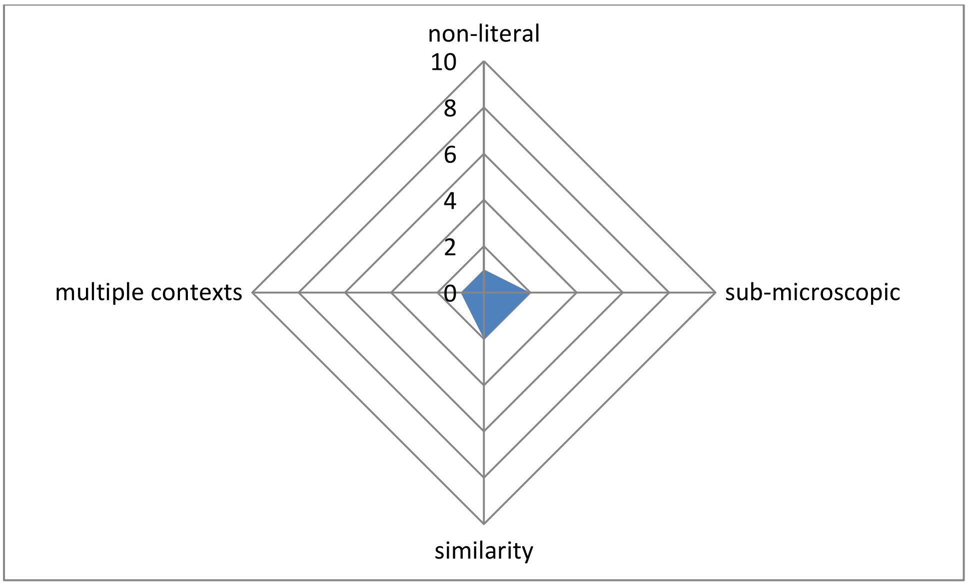


Figure 7.3 Linguistic demand for *gas* in four dimensions

This model of linguistic demand in four dimensions provides a mechanism for investigating the difficulties chemical words present to students. The larger the area of the graph the greater the overall linguistic demand. The shape of the graph indicates the dimensions of greatest demand.

In the initial CLDT, *solution*, *reduction* and *weak* were problematic. Figures 7.4, 7.5 and 7.6 compare the linguistic demand of these three words. All three graphs define large areas indicating high overall linguistic demand. *Reduction* and *weak* have similar shapes with highest demand in the non-literal and sub-microscopic dimensions. *Solution* scores less highly in the non-literal dimension because its everyday meaning gives some indication of its scientific meaning.

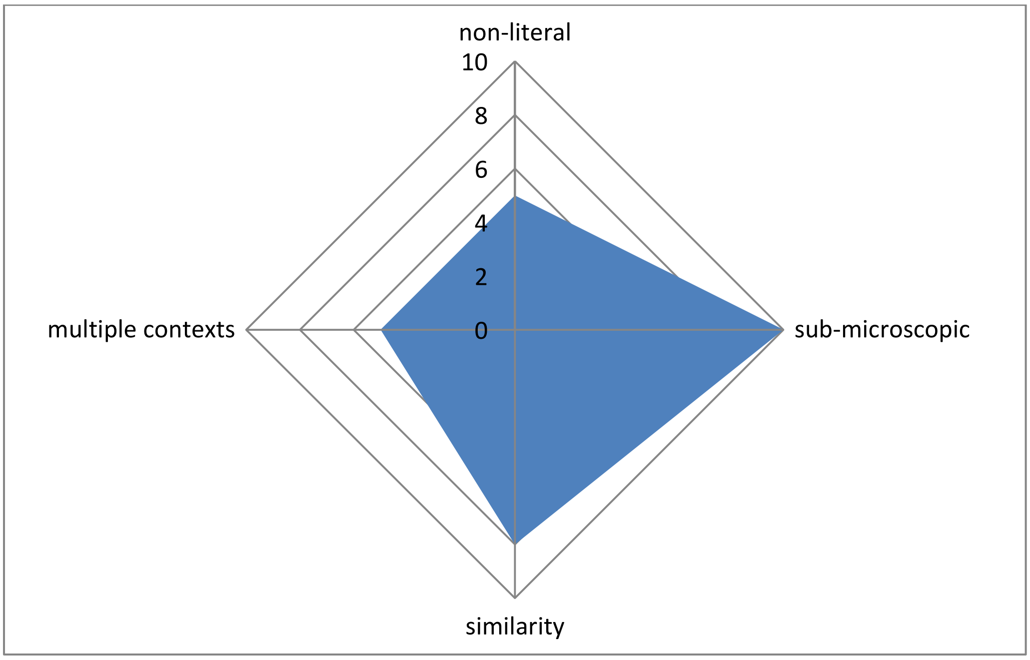


Figure 7.4 Linguistic demand for *solution* in four dimensions

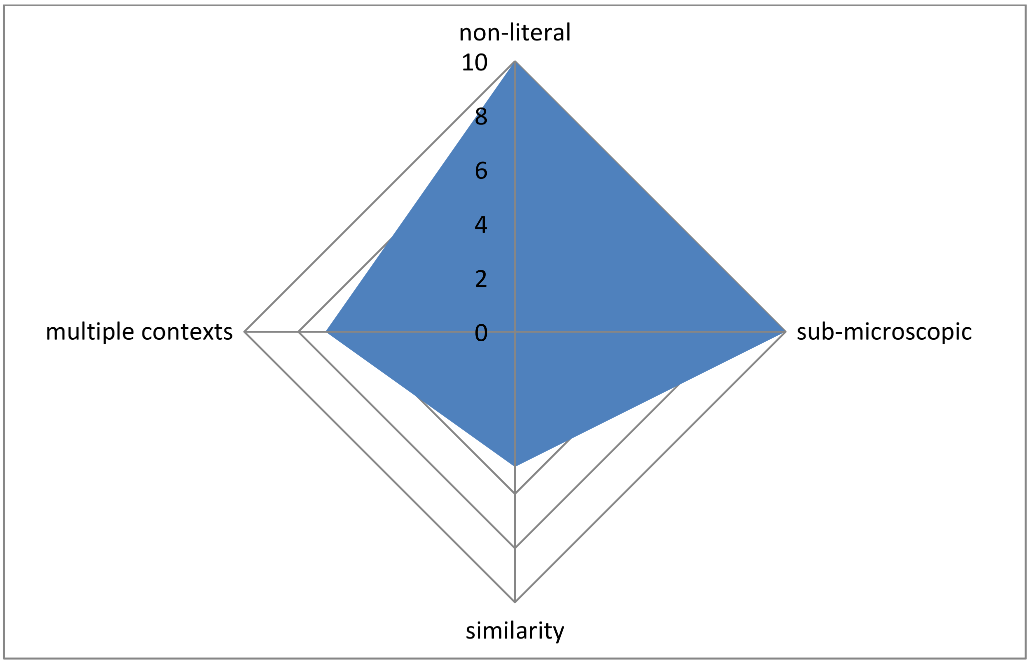


Figure 7.5 Linguistic demand for *reduction* in four dimensions

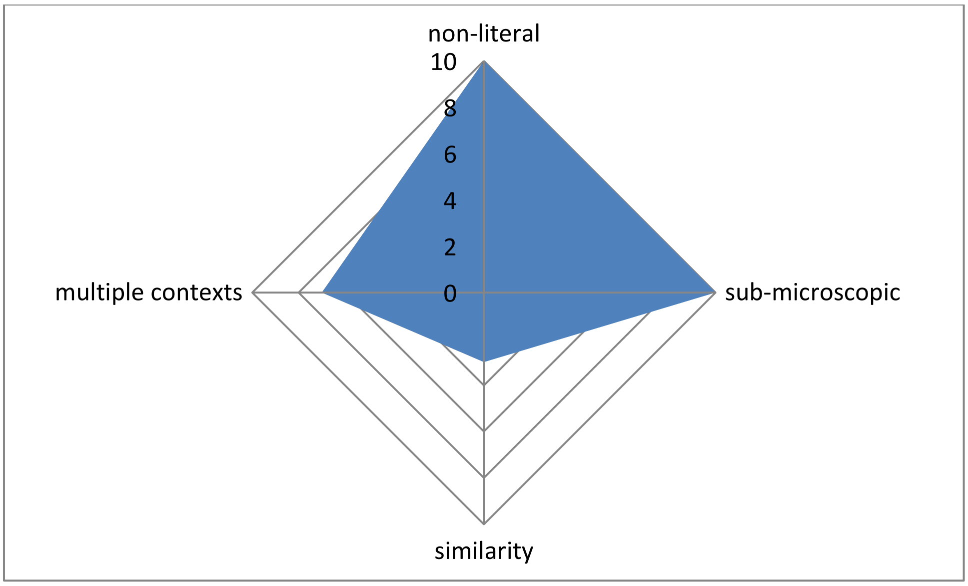


Figure 7.6 Linguistic demand for *weak* in four dimensions

Further research may establish that some dimensions are more significant than others. Chapter 2, for example, (Figures 2.3, p. 37) highlighted the importance of chemical language as a conduit between macro and sub-microscopic levels (Taber, 2013). The sub-microscopic dimension of linguistic demand may be more significant than the other three dimensions. Different dimensions may be more significant in different contexts such as interpreting text or participating in subject specific discourse.

This model can assess linguistic demand of resources such as Powerpoint® slides, handouts and textbooks. Powerpoint® slide in Box 6 (p. 50), for example, could be assessed for overall linguistic demand. Resources with high linguistic demand could then be reviewed to see if they can be made more accessible. Tools exist to measure readability of text such as the Coleman Liau index (Coleman & Liau, 1975) which measure text characteristics such as "words per sentence" and "word frequency". No tool exists, however, to specifically assess chemical linguistic demand.

7.6 Teaching with respect to the linguistics dimensions

Previous studies identified only one particular aspect of word difficulty such as dual meaning (Song and Carheden, 2014), or classified scientific words, for example Wellington and Osborne (2001). This study, however, is the first time a model has been proposed that analyses and classifies chemical language in multiple dimensions. This provides a mechanism for interpreting chemical words in terms of the linguistic demand they present to learners. By considering chemistry learning from this standpoint, there is the potential to move teaching practice towards a linguistically informed position in terms of the educators' awareness of chemical language and the teaching strategies employed to support students' difficulties. For example, if a topic contains numerous words with have high non-literal demand, teaching strategies may be employed to address this demand such as developing understanding roots of words. This means using strategies such as exploring origins of words as advocated by Sutton (1992, 1998; Chapter 2, Section 2.6, p. 56). The "*Aufbau principle*" for example, makes a lot more sense with awareness of the German meaning of "*build up*". The English literal meaning (i.e. *the "build up" principle*) should be used before introducing the less accessible German word. This study demonstrates that DDL is useful in addressing this dimension. Exploring common word roots and how they are used to form words in different contexts is helpful with reinforcing meaning. "Language of science" modules incorporating language, history and philosophy of science can deepen student understanding of the origins, evolution and application of scientific language.

For words with high sub-microscopic linguistic demand, such as *electronegative,* teaching strategies that help students relate to and visualise interactions are recommended. Role play, such as students representing electrons *and* modelling techniques to represent atomic structures and computer simulations are useful. These strategies are discussed further in Rees, Bruce and Nolan (2013).

Meanings of words with high linguistic demand in similarity and multiple context dimensions can be taught by providing regular opportunities for students to practise word usage. This occurs by developing a social constructivist learning environment which includes strategies employed here such as: word games, mini-whiteboards, discussion and peer feedback (Chapter 3, Section 3.3, p. 85). Teaching focusing on scaffolding activities that provide opportunities for students to practise their language usage (verbally and written) are valuable. Resources such as FOCUS allow investigation and exemplification of correct chemical language usage in multiple contexts.

7.7 Evolving chemical language and reducing linguistic demand

Language is dynamic and evolving and chemical language should evolve to make chemistry more accessible. For example, *sulfuric acid* is no longer referred to by its historic name *spirit of vitriol*. The multi-dimensional model proposed in this study provides a mechanism to identify terms that present high linguistic demand. Consideration should be given to changing these for words that present lower overall linguistic demand. *Electronegativity* for example, is problematic. Figure 7.1 shows high linguistic demand in non-literal, sub-microscopic and similarity dimensions. An accessible word which lowers linguistic demand would help students' learning. The sub-microscopic demand would be unlikely to change since the concept is focused at this level. An alternative term may, however, reduce non-literal and similarity linguistic demands. Interview students retained use of *pulling power* in relation to *electronegativity*. This informal term was accessible, so I recommend that *electron pulling power* is adopted in place of electronegativity for novice learners. Conceptual understanding may be more easily achieved with words that have lower linguistic demand. Consideration for removal of superfluous vocabulary offering no interpretive value, for example *Le Châtelier's principle* or *Markovnikov's rule,* is also helpful.

7.8 Language focused curricula and examinations

This study was undertaken within the context of non-traditional students. However, these issues are similarly important for all students' experience of chemistry. Teaching is influenced by the assessment. In England and Wales, A-level examinations (OCR, 2016) include definition questions such as "*what is an isotope*?" or "*what is a homologous series*?" These encourage rote learning of definitions with little development of students' interpretative linguistic skills. Alternatively, curricula could be developed that incorporated aspects of linguistic interpretation of scientific words. Questions such as "*why do the terms isotope and isomer contain the same prefix?*" permit development of linguistic skills leading to understanding of scientific words. This would influence teaching practice, positively promoting importance of metalanguage discourse and development of interpretative skills.

7.9 Conclusion

This study presents evidence that chemical language causes difficulties to non-traditional students across multiple dimensions namely; non-literal, sub-microscopic, similarity and multiple contexts. Chemical words present challenges within some dimensions more than others. Most challenging words have high linguistic demand in one or more dimensions.

The study presents evidence of how transitionary chemical interlanguage exists in potential undergraduates. Students engage in chemical interlanguage when they operate within their zones of proximal development (Vygotsky, 1962; Chapter 2, Section 2.7.1, p. 60) to develop their macroscopic and sub-microscopic understanding (Johnstone, 1991; Chapter 2, Section 2.2.1, p. 33). Different forms of interlanguage may exist that assist development of conceptual understanding (productive chemical interlanguage), reinforce misunderstandings (unproductive chemical interlanguage) or have limited effect (neutral chemical interlanguage).

Development of the chemical language diagnostic test (CLDT) provides a mechanism for students and lecturers to identify strengths and weaknesses in chemical language comprehension. Students can access relevant resources to improve understanding and lecturers can scaffold teaching activities to improve areas of weakness. Language focused resources including corpus linguistics and the FOCUS project have been developed and successfully embedded within a Foundation chemistry course.

I began this thesis by stating that teaching in Higher Education in the UK is entering a phase of transition. There is increased emphasis on teaching quality and widening participation. A skills gap exists in the UK with a desire to encourage greater participation in STEM subjects. Inevitably, educators delivering chemical education find the subject interesting and were successful chemistry students. On this basis, standard teaching practices persist because they were successful for the individual and colleagues delivering them. However, to extend the reach of chemistry to become accessible to a wider range of students there is a need to implement alternative teaching practices that actively promote this. Linguistic awareness and application of associated teaching practices as described in this thesis would make a significant contribution to engaging students who previously may have found chemistry incomprehensible.

7.10 Limitations

The CLDT is limited in the extent to which it probes "real" understanding of chemical language. This is evidenced by the fact that interview students scored highly in the fundamentals section but demonstrated confusion in use of *atoms* and *molecules* in the interviews. Furthermore, the test was limited to the areas it assessed, so would benefit by expansion to incorporate a reading comprehension exercise for example. However, this study intended to produce a test that could be used readily in a teaching situation.

The student explanations were limited to successive one to one interviews with the lecturer/researcher. Whilst every effort was made to make the interviews relaxed some students may have found this a pressurised situation. The interviews resulted in discussions running in particular directions and made comparisons of the scenarios between interviews problematic. In retrospect, a structured and definite approach to scenario discussions would have been beneficial. No data were collected from peer to peer discussion such as classroom based discourse.

Whilst large effect sizes were obtained for this study, it is not possible to attribute this solely to the teaching activities because the experimental design did not involve a control group not exposed to the teaching activities. The study was limited to the experience of non-traditional students in one institution. Interviewed students were a small volunteer sub-set of this group. Furthermore, it was difficult to investigate the experience of unsuccessful students who potentially may be of the most interest. Only one out of the six interviewed students was unsuccessful. Unsuccessful students were difficult to follow because they became uncontactable or attended intermittently.

The eye tracker study was limited to one task undertaken on two separate occasions with a relatively small sample of different sizes between the two sub-groups. This restricts the value of the data obtained.

7.11 Further research

Development of the chemical linguistic demand model requires exploration in relation to the impact of the different dimensions. The sub-microscopic dimension may be more significant in spoken or written situations. Further dimensions may be important to include in the model. Application to resources such as working with lecturers to analyse course materials or textbooks is also possible.

Further research explaining the existence of a chemical interlanguage would be valuable. A wider range of chemistry students may show similar learner “errors” as those documented in this study. Characteristic stages to interlanguage may exist that alter how a student progresses.

The eye tracker task indicates the impact of linguistic demand on reading comprehension. Reading remains an important study mechanism. Research investigating the impact of chemical linguistic demand would contribute information regarding student interpretation of text.

There was evidence that symbolic language was avoided in the eye tracker task understanding was problematic in the CLDT. The interview data showed limited usage of symbolic language. Further research could be undertaken to focus on this area of chemical language to determine if it presents greater challenge. Scientific scenarios could be designed that require an explanation at the symbolic level.

The FOCUS project currently utilises good quality student writing. It would be equally of value to construct a corpus of poor quality writing. This would provide opportunities to investigate common errors and misunderstandings that students make. A corpus of spoken chemical language would be a valuable resource for researchers and students. The corpus would provide opportunities for students to model how chemistry is spoken, gaining confidence by repetition and discussion.

The study was limited to discussions on a one to one basis in an interview setting. Investigations of classroom discourse may provide insights into the nature of chemical interlanguage during peer to peer discussions.

7.12 Concluding remarks

My motivation for undertaking this PhD was to gain a deeper understanding of the role of language in chemistry and to develop skills as an education researcher. This has proved to be a personal transformational experience that has afforded me a unique opportunity to reflect on pedagogy. Teaching and researching the same students is a demanding activity that requires perseverance, careful planning and good interpersonal skills. Developing understanding of Johnstone' triplet (Johnstone, 1991) and learning progressions (Corcoran, Mosher and Rogat, 2009), combined with second language learning theories of interlanguage (Selinker, 1972) and learner conditions (Spolsky, 1989) has greatly enhanced my interpretative skills from a theoretical viewpoint. Analysing data through these "lenses" has provided real insights into the complexity of chemical language and students' use to develop understanding. Pedagogy influenced by social constructivism places high linguistic demands on students. They are required to engage in dialogue within their zones of proximal development. The study has shown how this linguistic demand can occur in multiple dimensions. A chemical interlanguage exists that enables students to transition between macroscopic and sub-microscopic language and may assist or inhibit students' progression. The application of language informed teaching strategies such as corpus linguistics can help develop students' chemical language knowledge. However, students' attitudes and motivation may ultimately determine likelihood of success.

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A case study exploring developments in non-traditional potential undergraduates' understandings of chemical language.

Volume 2

Appendices

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Appendix 1

Interviews with Ferne.

Scenario 1 - States of Matter.

January 2014 - First attempt at states of matter scenario

CR	CCL	ICL
2	8	0

Language guidance	Comment number	I = Interviewer F = Ferne	Comment	Comments
Erm – an interjection used commonly to fill awkward space in conversations.	1	I	OK, erm, so I boil the kettle and steam rises up and condenses on the window. Can you explain to me why that happens?	
Sigh - to draw in and exhale audibly a deep breath as an expression of weariness.	2	F	(sigh) This is where I find it hard because I want to <u>have the right language</u> and sometimes I don't necessarily have it. This is where visuals come in isn't it?	Makes reference to not having the correct language.
	3	I	You mean in terms of doing diagrams?	
Yeah – an informal word for yes.	4	F	<u>Yeah, I think so.</u>	Refers to use of diagrams to help think about and explain the scenario.
	5	I	Well if you want to sketch a diagram then you can. Here you go sketch it on here.	

	6	F	I've forgotten the question you asked me now.	
	7	I	So kettle boils, steam rises and it condenses on the window.	
OK - an informal expression of approval or agreement	8	F	OK, so it's all about kinetic energy, (sigh) so you've got, how do you explain it? I did explain it but now you've put me under pressure In the kettle we've got liquid water which is molecules I think closely packed and they slide around or across each other or across not around. As the kettle boils then these molecules will be, well are going to gain kinetic energy, they are going to collide more. They are going to become a gas and fill the available space. Once they hit the window the window is possibly cooler than (p1) the air within the place (laugh). You can see where me problems lie now. OK, within the room once they hit there they are going to lose kinetic energy turn from a gas to a liquid.	Unclear explanation of the molecules moving around each other.
	9	I	OK, so…	
	10	F	I want to draw arrows…	
	11	I	OK, so there you are showing them as a liquid can you show them as steam?	
	12	F	Should I have things like this instead?	
	13	I	Ah well, yea, you could do couldn't you? Because what are you representing there?	
	14	F	A water molecule.	

15	I	Good.	
16	F	You are making us embarrassed now (laughing).	
17	I	Sorry, don’t mean to, just probing understanding.	
18	F	I am not going to do that, I’m not an artist anyway. So these are tightly packed and these are going to be further away and the window’s here and once these molecules hit the window they are going to lose kinetic energy because it’s cooler.	Unable to develop the explanation in terms of the interactions between the water molecules
19	I	OK, so the molecules have lost kinetic energy, what happens to the molecules? They’ve lost kinetic energy...	
20	F	And they turn back from a gas to a liquid.	
21	I	But what does that mean in terms of…	
22	F	So they are going to move closer together again.	
		END	

March 2014 - Second attempt at states of matter scenario

CR	CCL	ICL
3	24	2

Language guidance	Comment number	I = Interviewer F = Ferne	Transcript	Comments
	1	I	It's building on what we did before really. So you have a coffee cup with a hot drink, you blow on it and your glasses steam up.	
	2	F	Condensation again.	
	3	I	Can you explain to me why?	
	4	F	No (laughing). If you blow on it and your glasses steam up?	Seeks clarification about blowing on the coffee.
	5	I	Well the blowing isn't that important, let's just say I put the cup near my glasses and my glasses steam up.	
C'mon – abbreviation of come on – encouragement.	6	F	Ok, that's, c'mon I need definitive terms (laughing). So your glasses are relatively cold compared to the steam that is coming off the coffee.	
	7	I	Why is the steam coming off the coffee?	
	8	F	Because it is gaseous.	
	9	I	Why is it gaseous?	

	10	F	Because it's hot (laughing). Erm, with regards to steam then it would mean that the water has become a vapour and it has reached its boiling point.	
	11	I	So, what does that mean in terms of the water?	
Ugh - an exclamation of disgust, annoyance, or dislike.	12	F	Are we talking kinetic theory here? So the molecules of water have started to move around more vigorously, I'm looking for the right terms now (laughing), in comparison to a liquid or a solid and therefore as they are moving around (waves hands around). So you're going to compare us with last time and now I feel pressured (laughing). Ok then, in a liquid state then the water, ugh, has more kinetic energy than a solid which would be ice in the case of water and then in a gaseous state it forms what we know as steam and the molecules of water their hydrogen bonds break between them, intermolecular bonds, and they start moving about quicker.	Struggles to provide a cohesive explanation. Her response is quite disjointed.
	13	I	What are the nature of the intermolecular bonds between the water molecules?	
	14	F	What do you mean, the nature of them?	Confused by the use of the term "nature" in this context.
	15	I	So what sort of intermolecular bonds are they?	
	16	F	So (draws water molecules), I can put an H there can't I. We've got a lone pair of electrons on the oxygen which makes it slightly electronegative and the hydrogen's slightly positive. You draw them like that again. So therefore the hydrogen is. Is it the hydrogen attracted to the oxygen or are they both attracted to each other? However I'll just keep talking (laughing), because there's a permanent dipole? Then the lone pairs of electrons on the oxygen are attracted to and likewise the hydrogen which is slightly electropos, do you say electropositive? Electroneg.	Misunderstanding of electronegativity - confused with negative? No specific reference to atoms. Use of a new word - may

				mean positive?
	17	I	Well, that is interesting, it is not a term you really hear…	
	18	F	Slightly positively charged. But then these bonds between hydrogen and oxygen start to break and the molecules spread out more and gain more kinetic energy because they had heat applied to them. I don't know what to say now (laughing). These molecules of gaseous water hit your glasses or a window if you're not wearing glasses perhaps and they cool rapidly to a liquid and form a liquid state again and reform their hydrogen, sorry yea their hydrogen bonds.	

May 2014 - Third attempt at states of matter scenario

Joint interview with Linda - Language analysis for Ferne.

CR	CCL	ICL
2	15	1

Language guidance	Comment	I = Interviewer F= Ferne L = Linda	Transcript	Comments
	1	I	Explain the nature of the water molecule and how it changes as we go from solid liquid to gas.	
	2	F	We are talking about solid liquid gas.	
	3	I	Of the water, yeah.	

Hmm - a sound made when considering or puzzling over something. *Ah* – an exclamation.	4	F	So, (drawing diagram) you've got oxygen and two hydrogens, which is H two O, and we have a lone pair of electrons on our oxygen ~~molecule~~ and then there's some **inter**molecular forces between, I do have to draw really don't I? some hydrogen bonds. See I find it much easier to draw it or write it down than to say it sometimes. Hmm, I'm thinking (p2). We've got some **bent** water molecules and we've got intermolecular hydrogen bonds that allow them to form a crystalline structure. In liquid these are further apart and I can't remember, I'm thinking that they've still got hydrogen bonds but they are further apart, I'm going to have to google this. They're moving further apart and the same with the gas and kinetic energy increases which is why, ah! I don't know.	Refers to molecule rather than atom. Finds it easier to draw and write things down than to say things. A correct word but not typically referred to as a bent molecular shape in class where it was called non-linear (suggests term learnt from a different source).
	5	L	I think as a solid they occupy a bigger space because they are less likely to slide over each other and the hydrogen bonds keep them at a certain distance. where as in a liquid form, sort of, those bonds continuously break and reattach so it's kind of varying motion driven state. It's in a natural state in a gas its more spread out and those hydrogen bonds are broken and they move about randomly.	
	6	I	How do the hydrogen bonds come about?	
	7	L	Because water is a dipolar molecule meaning that the oxygen is more electronegative and it pulls the electrons from the hydrogen closer which makes it more negative nearer the oxygen and it leaves the hydrogen more exposed because the, on the positive side and attraction between the positive	

		hydrogen and negative oxygen is what creates the hydrogen bond.
8	I	What is the strongest bond on those diagrams there?
9	F	No idea.
10	I	Really?
11	F	Strongest bond?
12	I	Strongest bond on the diagram there.
13	F	Ah, covalent is that what you mean?
14	I	Which one on there would you say?
15	F	This should be equal to this to this. Is this what you are meaning? Well it is stronger than the hydrogen bond. Just wondering if there is something I am missing.
		END

December 2014 - Fourth attempt at states of matter scenario

CR	CCL	ICL
2	25	0

Language guidance	Comment	I = Interviewer F = Ferne	Transcript	Comments
	1	I	I am drinking my nice cappuccino, I blow on it and my glasses steam up (laughter). Can you explain why?	
	2	F	We're talking about condensation on your glasses. You have molecular motion of water. Well the water and milk in the cappuccino I suppose. The molecules are going to be more spaced out, are going to be gaseous hit the cool surface of your glasses and then they cool down and that loss of energy will put them back in to a liquid state (spoken quickly). Now I am trying to think about entropy and enthalpy and thermodynamics but I don't want to.	Introducing terminology from Year 1.
	3	I	Have you been doing a fair bit about that this term?	
	4	F	Yes	
	5	I	Go on then, have a little stab at it.	
Temp – abbr. temperature. *Me* – my. Colloquial north east England.	6	F	Basically If that's, ah, (p2) I wish I could remember everything like this so temp is decreasing therefore enthalpy which way is it going to go. I can see me[2] lecture notes but I can't remember. So that's going to be minus, so at 39 degrees, the entropy. I hate being tested like this, just did this on Monday but I'm feeling so rubbish. Sat for ten minutes in the test and couldn't think, couldn't even do stoichiometry. Never mind emotions affecting your learning I'm viral. I've felt unwell this week. I can't even think, I can see the slides.	Refers to illness affecting studies.

			Entropy is always increasing, I don't know. Can't we just talk about evolution instead, or the chemical synapse (laughing). So if that de [decreases], can't even work it out forwards, shall I just put some different, I need to, what is, what's kelvins? Kelvins is 270 something, 273.15. Wow wish I could just remember facts like that all the time but I don't know what values to put in here.	
	7	I	So which transition are you talking about here?	
Uh - a representation of a common sound made when hesitating in speech	8	F	I'm just talking about in general. In general if temp decreases then what else decreases with enthalpy and entropy, entropy's always going up apparently in this universe. Did you read about that, parallel universe where entropy is decreasing. I don't know if that's even possible because equilibrium, uh. We need less energy because it's less molecular motion. Sorry I don't even know today. These water molecules they're, erm, they're denser and they're widely spaced when they are solid. But then when they are liquid they're closer packed in water, in water only but when they are gaseous they move about but when they hit the glasses then they cool down and become closer packed and liquid and that's about all I can give you, I'm sorry.	Trying to apply new learning to this scenario but it is a very fragmented explanation that Ferne is unable to develop.
	9	I	what is holding the water molecules together?	
	10	F	Electrostatic attractions, I drew this the other day. I forgot those in me test though.	
	11	I	What are the dashes?	
	12	F	Hydrogen, no no, yeah, Hydrogen bonds.	

	13	I	What sort of thing are hydrogen bonds?	
Get my drift right? – do you understand me?	14	F	Do you want me to describe them? OK, it's all about the electron cloud around, erm, the oxygen. (p1) I'm not quite sure if this is how you are supposed to do it but you get my drift right? The electron cloud spends more time around the oxygen and attracts the hydrogen towards the oxygen because the oxygen is more electronegative and has more pulling power (*electron cloud drawn between the oxygen on one molecule and the hydrogen on another*). Is she talking rubbish or not?	Phrase retained from last year. Electron cloud drawn incorrectly. Correct use of terminology but incorrect understanding.
Cos - because	15	I	You're on the right lines but think about where you have drawn the electron cloud if you draw an electron cloud like that what have you formed between that O and H. Cos what you're saying there is that these electrons there on the oxygen move between the oxygen and hydrogen in a cloud like that.	
	16	F	Ah OK, because I'm not forming a covalent bond is that what you mean?	
	17	I	Yeah.	
	18	F	OK, so we'll get rid of the butternut squash then (*referring to the shape of the electron cloud*).	
	19	I	Where is the butternut squash?	
	20	F	Right OK OK yeah, obviously so we've the electrons here. I don't know which angles these are going to be at, (p1) for instance you've got your butternut squash here.	
	21	I	So why have you got the butternut squash?	

	22	F	Because oxygen is more electronegative than hydrogen therefore the electrons in the covalent bond spend more time around the oxygen than the hydrogen atom.	Good usage of electronegative in context.
	23	I	What is the hydrogen bond?	
	24	F	I don't even know if I know this – it will be in the depths somewhere.	Demonstrates a lack of confidence.
	25	I	Explain what you have there (*points to hydrogen bond*).	
	26	F	It's an attractive force between the oxygen and hydrogen because of the dipole between the other O and H. Is it that simple?	Provides a succinct explanation of a hydrogen bond.
	27	I	It's that simple. END	

June 2015 - Fifth attempt at states of matter scenario

CR	CCL	ICL
2	25	1

Language guidance	Comment	I = Interviewer F= Ferne	Transcript	Comments
	1	I	The kettle boils and then steam comes out and then it forms on the window pane, its water on there, can you explain why?	
Er - a sound made when hesitating in speech.	2	F	Condensation, so water from the steam from the kettle is the gaseous form of water the gas molecules have more movement. They have more kinetic energy (nervous laugh). It's been a while. So they're moving more more,	Tendency to drift away from

		you've also got, erm other molecules in the air. So you have carbon dioxide for example, er, diffusing toward, well diffusing all over the place I suppose. If your kettle is near the window then they are going to land on the window pane and cool down therefore lose kinetic energy and turn into a liquid state (*spoken rapidly*).	the main explanation
3	I	Why do they cool down?	
4	F	Because the glass pane is cooler than the air around them?	
5	I	Cooler than the air or cooler than? If the water molecules cool down the window pane must be cooler than what?	
6	F	Than the room temperature?	
7	I	Yeah, I suppose, it's the water molecules that cool down. Why would you not get liquid CO_2 or oxygen?	
8	F	I can't remember, their boiling points lower.	
9	I	Yeah, it would have to be wouldn't it?	
10	F	I can't remember what their boiling points are.	Is Ferne unsure of what is important learn?
11	I	Well you wouldn't expect to, you don't need to know that.	
12	F	In year 1 they want you to know stuff as well rather than just the principle.	
13	I	What changes in terms of the water molecules themselves let's take the water	

			in the kettle when it turns to steam what changes in terms of the actual water molecules themselves?	
	14	F	In what respect? You mean that...	
	15	I	Well when they go from liquid to gas what changes in terms of the water molecules?	
	16	F	The temperature of the water. The temperature of water which makes the, I can draw you a picture you know.	
	17	I	Feel free.	
Yer - you	18	F	You know what I am going to draw don't yer, the three boxes yeah, so they're tightly packed so that's in a solid state but with water obviously, we're not talking about a solid state are we? I could, yeah. See I have trouble with this. See their dipoles, I forget which one's positive and which is negative so these ones are widely spaced and your gaseous molecules are even more widely spaced. These ones are closer together that they can, uh, I know this but I don't know this. I need to just rote learn this don't I? See is it delta negative for oxygen?	Faltering response
	19	I	Why would it be that way round?	
	20	F	Your oxygen's more electronegative.	
	21	I	What does that mean, to say something is more electronegative?	
	22	F	Pulling power (laughter).	Term recalled from

			foundation
23	I	Nice bit of recall (laughter).	
24	F	The electron cloud spends more time around the oxygen therefore the shared-electrons are towards the oxygen, therefore with the energy that's (p1) put then it breaks these interactions.	Does not explain what electronegative means.
25	I	What interactions?	
26	F	The-di-poles	Refers to the interaction as the dipole.
27	I	What's happening between these water molecules?	
28	F	I can't remember this, I'll remember it when I get home. So yes, these molecules are not as tightly packed, see I can see the lecturer talking to me about molecular vibrations and you talking about mickey mouse-molecules but then the nitty gritty, ah. Help me out here.	Visualises memories.
29	I	This is great, so what is going to happen between that delta minus and that delta positive?	
30	F	They are attracted to each other	
31	I	Attracted to each other, yeah, do you remember what that attraction is?	
32	F	In what respect?	
33	I	Between those two, it's got a particular name?	

34	F	(p2) Hydrogen bonding?
35	I	Yeah.
36	F	Oh right OK, looking for the complex again.
37	I	So what happens to the hydrogen bonding when you go from a liquid to a gas?
38	F	There isn't any.
39	I	Where, in the gas?
40	F	Between the molecules.
41	I	In the gas?
42	F	Yeah.
		END

Appendix 2

Interviews with Ferne

Scenario 2 - Amount of substance.

November 2013 – First attempt at amount of substance scenario.

CR	CCL	ICL
2	1	0

Language guidance	Comment number	I = Interviewer F = Ferne	Comment	Comments
	1	I	I have 10 grams of lead and 10 grams of sodium. The lead has fewer atoms in it than the sodium, can you explain why?	
OK - an informal expression of approval or agreement	2	F	OK, so the lead has fewer atoms in it than the sodium.	
	3	I	Yes, that's right.	
Erm – an interjection used commonly to fill awkward space in conversations.	4	F	Well, so erm (p2) this is what we have just been doing (p2). So the lead atoms are bigger than the sodium atoms cos they weigh more.	
	5	I	What do you mean they are bigger?	
	6	F	Their atoms are bigger, they have more protons so their mass is bigger.	

	7	I	OK, so how do we describe the size of the lead atom compared to the sodium atom?	
	8	F	Erm, what do you mean? The lead is bigger than the sodium (laughs).	
	9	I	Yes but can we say this more scientifically?	
	10	F	Sorry, erm, I don't know.	Unable to develop explanation
	11	I	OK, thank you.	
			END	

March 2014 - Second attempt at amount of substance scenario

CR	CCL	ICL
3	7	1

Language guidance	Comment number	I = Interviewer F = Ferne	Comment	Comments
	1	I	I have 10 grams of lead…	
	2	F	Oh man, don't make us do maths…	
	3	I	And it has fewer atoms in it than ten grams of sodium. Why is that?	
	4	F	(p2) Why didn't you tell us you need the periodic table?	
	5	I	Well, it could be any substance…	

6	F	I know, where's lead? Down here somewhere, there you go, it has a higher (p3) (writing) how do I say it again? What is it called? Molecular, relative molecular mass. Trying to find the words now.	States molecular rather than atomic mass.
7	I	Is it a molecule we are dealing with?	
8	F	Ahh, atomic mass, OK, thank you, yes. Actually, this is one thing as well cos I've learnt all this stuff in teaching block one and what I'm scared of is forgetting it all again. So I'll be going over it in the summer.	Corrects after prompting.
9	I	OK, so we've got a different relative atomic mass. That's what you said.	
10	F	Ahmm, therefore (p1) am I talking about moles? Erm, the (p1) molar mass in lead will be less than the molar mass of sodium.	Incorrectly states molar mass of lead is less than sodium
11	I	What does molar mass mean then?	
12	F	So, one mole of lead will be the, well it's the equivalent of 6.022 times 10 to the power of 23 atoms in (p1) well in lead.	
13	I	How would I know if I had that many atoms of lead?	
14	F	Because it would be, how many atoms? One mole?	
15	I	One mole of atoms	
16	F	Because it would be the same as its relative atomic mass in grams.	Demonstrates good understanding of the relationship between amount

			of substance in moles and mass in grams.
17	I	OK, so coming back to the original thing then, so you’ve ten grams of lead and ten grams of sodium, why would the lead have fewer atoms in it?	
18	F	Because, because lead has a higher relative, is it not circular? Because it has a higher relative atomic mass to sodium.	Now states the relationship the correctly.
19	I	Therefore?	
20	F	Therefore, one mole of lead is greater than one mole of sodium or heavier in grams.	
21	I	So 10g of lead would contain what compared to ten grams of sodium.	
22	F	Less than…	
23	I	Less what?	
24	F	Lower moles, less moles.	Struggles with the correct comparator.
25	I	Fewer moles, yeah.	
26	F	Fewer, that’s the word, right OK.	
27	I	OK, brilliant.	
		END	

December 2014 - Third attempt at amount of substance scenario

CR	CCL	ICL
3	17	2

Language guidance	Comment number	I = Interviewer F = Ferne	Comment	Comments
	1	I	I have ten grams of lead and ten grams of sodium.	
	2	F	Are you going to make me do maths?	
	3	I	I'm not really going to make you do maths but in the ten grams of lead I have fewer atoms than in the ten grams of sodium.	
Aha – an affirmation	4	F	Aha.	
	5	I	Why is that?	
	6	F	Because lead has a lower erm sorry a higher atomic weight sodium has a lower atomic no sorry, you know what it is these guys here just don't care they say weight rather than mass.	Refers to atomic weight rather than mass because that is the term that has been used this year.
Oh – an exclamation	7	I	Oh, this is interesting.	
	8	F	So in any case, sodium has a lower atomic mass than lead. I don't know what the atomic mass is…	
	9	I	It doesn't matter but you've got the point.	

10	F	So, basically, erm if we said, for instance, if something has er, atomic mass of 100 grams or something has an atomic mass of 10 grams or if I phrase it like that. So for instance, ~~if lead had (p1)~~ is it atomic mass or atomic number? the top one number massive, see?	Omits use of the word "relative". Gives atomic mass units of grams. Recalls a method for remembering which number is the relative atomic mass.
11	I	Brilliant.	
12	F	Remember some things. That would be nought point one, not capital M, nought point one moles and this would be one moles and this is, hold on (p1) and then due to Avogadro's constant or number then we would have fewer atoms here because that would be six point zero two two times ten to the twenty three times nought point one. And this would be, ah, I should do it the other way round shouldn't I?	Applies correct units. Shows good understanding of Avogadro's constant
13	I	Brilliant, you know that is the best answer anyone has ever given me to that question.	
14	F	Is it really?	
15	I	Yes, can I come back to this one here? This hundred gram and ten gram here what would you call those?	
16	F	Erm, well I said atomic mass didn't I? So basically we have atomic mass is equal to (p1) are we talking about carbon 12 aren't we so that's what we relate it to.	Shows awareness of carbon 12 but does not elaborate on relative atomic mass.

17	I	Right so what's wrong with what you have written here?	
18	F	Because I'm using grams rather than erm (p4) is it amu? Atomic mass units which is what you taught me.	Refers to unit term not used in foundation.
19	I	Well I didn't actually.	
20	F	I'm sure I must have read it then.	
21	I	We put a word before atomic mass last year?	
22	F	Relative.	
23	I	Relative so are there any units?	
24	F	(p2) Erm, then no there aren't.	Appears to recognise the significance of relative.
25	I	There is another way you could have expressed that using grams but not using just grams on its own?	
26	F	Grams per mole	
27	I	Yeah, and it has a name?	
28	F	Daltons	Refers to unit term learnt this year rather than molar mass.
29	I	No, for this type of unit grams per mole we had a way of referring to that? (p5) No? Molar mass?	

	30	F	OK, yes of course, aha. END	

June 2015 - Fourth attempt at amount of substance scenario

CR	CCL	ICL
4	12	0

Language guidance	Comment number	I = Interviewer F = Ferne	Comment	Comments
	1	I	I have ten grams of lead and ten grams of sodium. Ten grams of lead contains fewer atoms in it than the ten grams of sodium, can you explain why?	
	2	F	Avogadro's number, constant. That one mole is, well, you use it with regards to, well, it's comparative. You say that twelve grams of carbon is equal to one mole of carbon so everything is compared to carbon twelve and how many atoms are in twelve grams of carbon. So, therefore, if you have, I can't remember the, see look I have to think about the atomic number and atomic mass. So it's atomic mass that we talk about, erm, but I don't know what that is of lead but obviously lead has a higher or a greater atomic mass than sodium.	Omits relative *i.e.* relative atomic mass. Corrects comparator to something that she feels is more appropriate.
	3	I	OK, very good.	
	4	F	Oh we all remember Avogadro's number (laughter), you need to ask Steph about that. When she was revising her son asked her about it and she	A memorable event appears to have helped recall.

		explained what it was and he was repeating it to her. I know what Avogadro’s number is (impersonating child).	
5	I	So lead has a greater atomic mass…	
6	F	Therefore, the ten grams of lead will have fewer atoms in it than the sodium.	Demonstrates a good understanding of the relationship between amount of substance and mass.
7	I	OK, thank you.	

Appendix 3

Interviews with Ferne

Scenario 3 - Benzene.

January 2014 - First attempt at benzene scenario

CR	CCL	ICL
2	17	2

Language guidance	Comment number	I = interviewer F = Ferne	Comment	Notes
	1	I	Can you explain to me why benzene needs a catalyst to react...	
	2	F	No (laughter), No I'm going now.	
	3	I	and cyclohexene and phenol don't?	
[1]*Patty* – American word for a beef burger. [2]*Yer* – you. [3]*Crap* – (slang) rubbish.	4	F	No, no I can't just speak it out. This is what I find hard (Starts drawing). Not very good at drawing can you tell? So this represents three pi bonds. So if you've got sigma equals single pi. Single is the filling in the pie or the patty[1] in the burger but I thought the pie analogy sounded quite good. This is delocalised electrons – 3 bonds delocalised. How do you draw that? I can't do 3d. This kind of like big cloud haven't yer[2] underneath and above (laughter). It's so crap[3]. I want a burger but it doesn't really relate to that. This is an electron, would you call it an electron cloud? So an electron cloud moving around and you don't have one area of higher electronegativity. See I'm still getting this into my head you	Transitional understanding. Ferne attempts to describe the pi bond formation in a C=C and is using analogies with a pie filling or a beef burger between two buns to visualise the bonding (self developed analogies). Incorrect term – confused with electron density hence reference to inducing a

			know. It isn't in there yet not completely. Help me out.	dipole.
	5	I	What do you mean there isn't a higher electronegativity?	
	6	F	So you can't induce a dipole. Bit of a mess. So you've got one double bond in cyclohexane – I'm not explaining this very well. Hexene or hexane? Hexane.	Unsure of understanding of suffixes "ane" and "ene".
	7	I	Really? Double bond, double...	
Yeah – an informal word for yes.	8	F	Yeah yeah sorry, I think I've written that on my sheet mind, hexane. Yeah, this double bond (p1). So you've got something coming along, a species coming along. I don't know I go blank. I'll be alright in an exam if you ask us, because you won't be asking us (laughs).	Appears to feel pressure of being interviewed and is flustered. Technical word choice - species.
	9	I	Structure there, so you've the delocalised electron cloud there – how does it relate to the bromine molecule? Why will the bromine molecule not react with that one?	
Ooo – a sound produced when stuck about what to say next.	10	F	(p1) What was I reading (p2) about electrons and how they move about and you cannot, it was the difference between an orbits and orbitals. So in an orbital, then the electron in a (p1) spd (faint laughing). In an **s** orbital it can be anywhere within it. I see this like that as well that the electron can be pretty much anywhere but here you can't have that, it's fixed and ooo, I don't know, I'm sorry. I'm rubbish.	Confusing chemical language. Lacking confidence
	11	I	No you're not at all.	

	12	F	I know I'm not, I just can't explain it which is part of the problem.	
	13	I	Well I think we are kind of going to a bit of tangent really to actually the point. So you've described the structure of benzene…	
	14	F	I need this background information in my head to understand it...	
	15	I	You've got the structure of the cyclohexene but why can that one have an effect on the bromine.	
	16	F	Because this bond can be broken quite easily in comparison to these delocalised bonds.	Third use of delocalised collocation (electrons, cloud, bond)
	17	I	Yeah, OK but what effect does it have on the bromine? (p2) no idea?	
Yer - your	18	F	I probably do but (laughs), bromine (starts drawing), right, then you've got yer I don't know – it's quite frustrating sometimes this maturity (laughs).	
	19	I	Can you say anything about the phenol?	
	20	F	I was doing this and I've done it on my little thing for you. Can I have it back? (draws sketch). That's why but I can't put it into words. See I want to do that and I want to do that (draws on diagram) but I don't know if that is right or not (p1) and that's where I kind of…	Ferne is unable to develop a cohesive explanation relating to the phenol molecule inducing a dipole in the bromine molecule.
	21	I	So you've drawn two dots above one of the bromine. What does that indicate?	

	22	F	But then I can't remember which ones, so that should be negative because that's electrons and that should be positive because there is no electrons, OK?	
	23	I	OK	
Gonna – going to *Sigh* - to draw in and exhale audibly a deep breath as an expression of weariness	24	F	And then (p1), then I get stuck here you see because that's gonna (sigh) and that's where I get stuck again you see. So it may come eventually. END	Ferne is unable to progress the explanation further

May 2014 - Second attempt at benzene scenario

Joint interview with Linda - Analysis undertaken on Ferne's comments.

CR	CCL	ICL
2	18	1

Language guidance	Comment number	I = Interviewer. F = Ferne L = Linda	Comment	Notes
	1	I	Explain why benzene requires a catalyst to react with bromine whereas cyclohexene and phenol do not.	

	2	L	Ah, benzene is more stable, more stable molecule because the electrons which are, the delocalised electrons sort of move freely but in an organised manner so the polarity is evenly distributed. Whereas this one, I'm not going to try and pronounce it. In this one there is more imbalance because the double bonds, um, the charge is differently spread so the sigma and pi apply slightly differently, so it doesn't need, so if there an electro-phi-lic molecule comes in a reaction is more likely to react whereas with the benzene something needs to initiate the change. I hope I'm explaining it correct. I think that's about it but I still need to revise it properly. It's all about distribution of charge.	
	3	I	anything you want to add to that Ferne?	
	4	F	No (laughter).	Ferne is prepared to let Linda take the lead.
	5	I	What about the phenol.	
	6	L	Does it need a catalyst or doesn't it, I can't remember.	
	7	I	It doesn't need a catalyst. Benzene does but phenol doesn't.	
	8	L	The OH group itself is sort of slightly destabilises the molecule because it is a negative, no it's got two a dipolar molecule in terms of the OH if its attached to the ring it will cause imbalance among the electron distribution.	
Erm – an interjection used commonly to fill	9	F	It activates the, sorry I was just thinking. It activates the (p1) delocalised, what is the benzene ring , this erm, what's it called these electrons. The lone pair of electrons activates this ring	Incorporates a systematic phrase

awkward space in conversations.			therefore it, erm, this becomes involved, see I’m kind of getting there but not using the right terminology, uh, I’m not putting a curly arrow right. I am just saying that is involved here but then you get this kind of thing. Is it the electron cloud so these electrons and these electrons here react together and then that’s where I stop, sorry.	A faltering explanation Incorrect term – react instead of interact
	10	I	But why does that mean that I can put bromine water with this one and it will react compared to this one when it won’t?	
	11	F	Is it because these electrons are moving over to this area as well as these ones moving over these areas. I’ve revised it but I still can’t remember it all. Is it because the distribution of the-electrons will induce a…	
	12	I	Induce what?	
	13	F	A dipole on the bromine.	Does not specify a bromine molecule.
	14	L	Different molecules and different, er, atoms have a different electronegativity. So if it needs to be above a certain level or below a certain level so if its bromine is more electronegative so it is more likely to react than if it’s something less electronegative.	
	15	I	So with that bromine molecule there Br and Br is the electronegativity irrelevant or significant?	
	16	L	Yeah, because they are bigger electrophiles than the OH – something to do with how strong electrophils they are. Which card trumps which card.	

Me - my	17	F	I am just getting a bit confused about me positive and negative because I know that these electrons here are going to go here but I can't remember which ones. If those electrons there will it be delta negative, delta positive?	Confused about the effect of the electrons on the charge of the molecule.
	18	L	I think the positive is on top because the pi bond is negative and pi would attract positive.	
	19	F	Yeah but then why, is that right then or not.	
	20	I	Ferne is circling a lone pair of electrons on the bromine atom.	
	21	L	I think you are over complicating it now.	
	22	I	Why do you think she is over complicating it?	
Kind a – kind of	23	L	Pair of electrons here but you don't really need it. Otherwise, you kind a when you write it, it might get confusing. The line itself implies its double electrons. The question is why does it react not how does it react.	
	24	F	I think you need both.	
	25	I	Why did it then?	
	26	L	Because bromine is a stronger electrophil than the OH group itself and so it will take over its place and become neutral…	
Went off on one – phrase used to	27	I	Now you see, that isn't the reason. It's a really interesting answer. There was a bit you said about inducing a dipole and then you	

refer to when someone starts to drift away from the point.			went off on one a bit here.	
	28	L	This one’s positive and this one’s negative and then it will kick out the hydrogen, actually the oxygen will stay here, right?	
	29	I	Well, now you’re quite hung up on this but no reaction happens here.	
	30	F	This lone pair of electrons just activates the ring. Which is why you don’t need the catalyst.	Repeats systematic phrase. Demonstrates correct understanding of process.
	31	I	That’s right.	
	32	L	Because it is three different rings they are all slightly different so it is understanding the difference from one to another. Ok so where would the bromine join?	
	33	I	On to here.	
	34	F	So, (p2) I need to get this straight in my head, electrophilic, nucleophilic.	Unqualified use of terms.
	35	L	Actually it’s much more simple than electrophilic at the moment. Is that correct?	
	36	I	Well electrophiles are what we have focussed on.	

	37	L	You remember bits and I remember bits and we bring them together. END	

June 2015 - Third attempt at benzene scenario

CR	CCL	ICL
2	21	3

Language guidance	Comment number	I = interviewer F = Ferne	Comment	Notes
	1	I	Why does benzene require a catalyst to react bromine whereas cyclohexene and phenol do not?	
	2	F	Well, I can't remember about cy-clo-hexene, I can't remember its chemical structure but benzene basically has nothing that is erm, what's the word? Phenol has an OH group a hydroxyl group which will react with it will be water soluble so it will react with anything that can be a bit like water (laughter).	Confident use of OH group and affirms with hydroxyl term. Deviates to start talking about solubility in water
	3	I	Right.	
Oh – an exclamation *Ah* – an exclamation	4	F	With benzene it's Mr Kekule his snake and his bonds, oh, ah, I can see it in my mind's eye but I can't explain it in words.	Association with a snake recalled.

	5	I	So what sort of thing, what sort of structure can you see in your mind's eye? What sort of shape is it?	
	6	F	A hexagon with six carbon atoms on it that are attached by one singular erm, what's it called? It's not a pi bond it's the other one, sigma bond.	
Ahmmm - an affirmation.	7	I	Ahmmm.	
	8	F	And then three moving pi bonds so it kind of has, 1.5, ah, I don't know, 1.5 bonds per carbon so there's two one two one. You know what I mean.	An opportunity here to use more chemical language *e.g.* delocalised electron cloud but Ferne prefers to use a simpler form. Note how there is no reference back to analogies used in the first interview.
Yep – an informal word for yes.	9	I	Yep, ahmmm.	
Me - my	10	F	If you asked me to type it down then I would probably be better. Something to do with me brain and fingers rather than me brain and speech.	
	11	I	OK, so we've got this hexagon and we've got these pi bonds around but how does that compare to the phenol then?	
	12	F	So phenol has erm, instead of a hydrogen on each carbon kind of sticking out from the hexagon then we have a hydroxyl group which replaces the hydrogen and then that part has a different electronegativity? So that your electron cloud will be (p1) be different (laughter). It bonds to the OH group. Is the more	

			electronegativity yea oxygen is more electronegative than hydrogen. Isn’t it? I can see it in my head.	
	13	I	Ahmmm, but how does that mean that you know the phenol would react with some bromine water where as the benzene...	
	14	F	Because, hold on, bromine water, so it’s water which means it’s aqueous so it would be water soluble so the OH group is erm, is it slightly ah, it has a charge. Slightly charged and so is water and then they will react more readily whereas, sorry, what’s it called? Benzene doesn’t have that.	Ferne has returned to ideas about solubility and seems to see this as a reason why they will react.
Right – being used as an acknowledgement rather than an affirmation.	15	I	Right.	
	16	F	And therefore, I don’t know the correct term but basically the bonds are less likely to react as can be...	
	17	I	So which bond in the benzene, or the phenol for that matter would react with the bromine?	
	18	F	I’m trying to see me little pictures in me head, erm, which bond?	
	19	I	Yeah, so when it actually reacts so we get reacting with the bromine which bond is it in the phenol that is reacting?	
	20	F	In the phenol, is it the bond between the carbon, carbon and the hy-drox-yl group? I’m trying to think of your little dots and yer	

			electrons and stuff (laughter). I can see these things and in the little booklet that you gave us but I can't remember the details as such.	
	21	I	Yeah, OK.	
	22	F	You've got electron sub-sti-tu-tion and electron addition and all that stuff.	Interlanguage – electron substitution rather than electrophilic substitution
	23	I	Ahmm, OK.	
	24	F	That carbon there with the OH group on. Do you class that as carbon one?	
	25	I	With the OH on? Yeah.	
Cos - because	26	F	Right OK so I'll say that one then. It's not between the oxygen and the hydrogen is it? Ah, I don't know. No cos the oxygen is going to be is it delta negative, ah I always forget which way round but I think it should be the hydrogen that should be delta positive.	Deviating from the question and Struggling to recall the polarity in an OH group.
	27	I	Alright let's move on to the erm, cyclohexene. Erm, how is that structure different to the benzene? Do you remember?	
	28	F	Ah, hex**ene** so it's an alk**ene.**	
	29	I	Yep.	
	30	F	So it has-one-doub-le bond but hex means five does it no hex means six doesn't it?	Corrects a simple error.

31	I	Ahmm.	
32	F	Try again (laughter) erm so yes it's going to be six carbons but then, ah...	
33	I	OK, so basically you've got one double bond in that hexagon of six carbons.	
34	F	So if it's one double bond I am trying to work out ah, no I don't know. I can't recall. I know that must have something other than a-hydrogen on one of their cyclic carbons.	Incorporation of relevant terminology.
35	I	Why must it have something other than a hydrogen on if it's cyclohexene?	
36	F	(p1) yeah, it wouldn't so it has to be something to do with the double bond then.	
37	I	So I just add the bromine water. I don't if you remember what happens when I add it to a substance like that?	
38	F	Is that when it loses its colour?	
39	I	Yeah, that's right, loses its colour, yeah.	
40	F	I can see you in the lab doing it but I can't remember the details yer see.	
41	I	So no idea what effect that molecule has on the bromine molecule?	

42	F	So the bromine is a diatom, is that correct? Ah ok so then yep that double bond is going to react with the bromine and the bromine is going to attach to that double bond.	Interlanguage – diatom – diatomic molecule. Correctly recalls the reaction but no terminology used.
43	I	Right, so what effect does it have on the bromine molecule which means it can do that?	
44	F	What effect?	
45	I	Yeah, so...	
46	F	Do you mean with electrons?	
47	I	Yes.	
48	F	Right, OK so, erm, is this (p1) ah, I can these little lines with dots and arrows and stuff but I can't remember which way they go. You would have (p1) no, no.	Unable to formulate an explanation
49	I	OK, so you said that bromine is a diatom so what do you mean by that?	
50	F	You've got sharing electrons.	
51	I	Right so we've got two bromine atoms sharing a pair of electrons so if that molecule, that diatomic molecule there approaches the cyclohexene does anything happen to that molecule, that bromine	

			molecule?	
	52	F	As in?	
	53	I	As in the electrons that are bonded between those two atoms.	
	54	F	I can't even remember which blooming electrons they share (laughter). My memory's not that bad honestly I just have a lot to remember. Erm, so basically is it something to do with things bumping in to one another.	Unable to explain about the bromine molecule being polarised
	55	I	OK, but in terms of an effect on that molecule, no particular idea really what effect the cyclohexene has on that molecule?	
	56	F	I am not quite sure, cyclohexene, why does it have an effect on it? So I'm thinking is it, erm, trying to find the right words, erm, electrons, electron clouds and where they are moving to and erm, it's that double bond on the cyclohexene. I can't remember what it's called, this is the problem, I want to be able to say the right things.	
	57	I	You can't recall the right words now?	
	58	F	No, I'm going to go upstairs and have a look.	
Okidoki – an extended form of OK.	59	I	Okidoki.	
	60	F	I can remember some hydrogen sulphate or something, not necessarily to do with that reaction but in that whole area. Is that right?	Reference to a rather obscure connection with the topic

61	I	Erm, I think you might be thinking of sulphuric acid.
62	F	Yep, that’s it, that’s it, sorry.
63	I	No, there’s no wrong answer you see.
		END

Appendix 4

Interviews with Linda

Scenario 1 - States of Matter.

November 2013 - First attempt at states of matter scenario (Joint interview with Nina - Analysis undertaken on Linda's comments).

CR	CCL	ICL
2	8	2

Language guidance	Comment number	I = Interviewer. L = Linda. N = Nina	Comment	Notes
	1	I	I breathe on to a cup containing a hot drink and my glasses steam up. Can you explain why that happens?	
Er - a sound made when hesitating in speech.	2	L	Well, er, as we know a hot cup would er, the heat means, er, the heat means there is a high kinetic energy going on. And when you blow into cup you are trying to cool it down, especially on the top, er, sorry I need to , er. It cools the surface, and as you cool down the surface, er, its more (p1) the particles on top the water that (p1) (*unint - in the gaps?*), er, and in the contact with the air and the blowing which cools itself more and in terms of the condensation (*unint – I'm very sorry?*).	Transitionary sentence. Lots of faltering and pausing. Loses flow of the explanation. Unqualified usage of term.

	3	I	No, no, that's ok...	
	4	L	I just need to think a long time to kind of put it in to words.	
	5	I	Anything to add?	
	6	N	I think because of the evaporation. That as a, like, how d'you say, The heat is when we put on, like, not lid of something the heat can evaporate and then its, er, straight away it merge with the oxygen in outside air when it merge the water the first level of water start cooling down cooling down because all the heat came out as evaporate.	
	7	I	So why does the condensation form on the glasses?	
Yeah – an informal word for yes.	8	N	Yeah, yeah, condensation, I don't know about that one.	
	9	I	So we have got the particles evaporating and they kind of gone in to the air and we've kind of got this last part.	
	10	L	The glasses are cold so, when they, on contact they liquidify the molecules ~~get attached~~ to each other and condensation is formed.	Not an English word – should be liquify. No mention of how the molecules attach.
	11	I	Why do the molecules do that?	

12	L	Erm because they, er, lose kinetic energy because they stop, well they don't stop vibrating but their, er, volume of movement is reduced.	Pauses to think of the word and chooses volume (rather than amount?)

END

February 2014 - Second attempt at states of matter scenario

CR	CCL	ICL
3	26	5

Language guidance	Comment number	I = Interviewer L = Linda	Comment	Notes
	1	I	Can you explain to me what happens when a kettle boils, steam comes out and condenses on the window. Why is that?	
Erm – an interjection used commonly to fill awkward space in conversations.	2	L	When the water is boiled it has very high kinetic energy and as a result the molecules move much more, erm, and they move so much that actually they overcome their hydrogen bonds and they split into the air. In the air they cool down but also in gaseous gaseous form they, er, transfer, diffuse in to the rest of the room but when they reach the window the window is cold and, as a result they lose their kinetic energy and they stop moving as much and on the window there are, when there are a lot of water molecules because of their attraction to each other because of their polarity and they create droplets which appear as condensation so it's basically kinetic energy, so.	Confident use of language Using the term polarity appropriately.
	3	I	Ok, just pick up on what you said about polarity...	
Um - hesitation.	4	L	They, erm, attract each other the, um, molecules and form droplets which attract each other by hydrogen bonds.	

	5	I	OK, but what does the polarity bit mean?	
Binded - bonded	6	L	The molecule has an uneven charge so where the hydrogen is left exposed because it's electron's binded to the oxygen it forms a positive side at one end and, er, the oxygen because of the two extra electrons it has got more concentration of negative so as we know negative attracts positive hence it's bond.	Regards the hydrogen as being exposed by the movement of electrons. Appears to regard the hydrogen as losing its electron to oxygen. Suggests the covalent bond is an attraction between opposite charges or may be referring to hydrogen bonding. Note the general absence of reference to atoms specifically e.g. hydrogen atoms.
	7	I	So what connects the hydrogen and oxygen atom?	
	8	L	Er, cova, covalent bond sharing electrons.	
	9	I	So those two electrons, what are they doing in terms of the oxygen and hydrogen?	
	10	L	Each, erm element, er, needs to fill its outer shell the oxygen needs two more electron to have a full outer shell of 8 electrons though hydrogen only has one on the outside and the first shell is always two electrons so it would need to achieve that balance and (p1) hence then joining together.	Anthropomorphism Hesitations increasing. Starts trying to describe why the covalent bond forms in terms of electron configuration
	11	I	What are the two electrons doing that form that bond?	
	12	L	They have electronegative for, via, they share, erm, they share the	Considers using electronegativity but

		nucleus from both atoms so they kind of act the electrons act to stabilise both nucleus in the middle, how do I say it.	is unsure how to apply it. Appears to think electronegativity is a property of the electrons. Nucleus – should be nuclei. Suggesting the electrons stabilise the nuclei – meaning is unclear.
13	I	OK.	
14	L	I think that's it.	
15	I	How do we end up with the polarity?	
16	L	Because the, erm, electrons they have negative charge they repulse each other so position themselves as far as possible from each other which they, erm, they take certain position unless they are two electrons and then they, kind of, conjoinedly form the sort of a pair conjoinedly or the way they move. So once they are in pairs they repulse each other. The repulsion theory, that's what it is and take a position and as we know lone pairs repulse more than joined pairs and er...	Unable to provide an explanation of polarity and is now explaining VSEPR theory. Meaning unclear.
17	I	OK, so that is the repulsion between the different pairs of electrons but what I mean is those two electrons between the oxygen and the hydrogen.	
18	L	Oh, OK.	

19	I	OK so we've got an OH bond and what you said is that there is a polarity in that bond yeah?	
20	L	In the molecule, yeah in the bond, yes the two electrons are negative and the nucleus is positive then the negative is shared between the oxygen and the hydrogen because of the electronegativity.	Interlanguage – attempt to use the term electronegativity but incorrect.

21	I	Ok so those electrons are shared between those two atoms but how do we end up with a polarity in the bond.	
22	L	(p1) Between the oxygen and the hydrogen? (p1) It's not in the bond it's sort of an overall charge.	
23	I	In the molecule?	
24	L	In the molecule yes.	
25	I	OK so in the overall molecule, then how does that polarity come about?	
26	L	Er, It's the two lone pairs, er, next to each other the two joined pairs are covalently bonded are on the other side which leaves one side, erm, more with the bigger charge than the other one and because oxygen is a larger molecule it's got greater pulling power than the hydrogen so which leaves the hydrogen exposed hence its positive side...	Struggling to find the appropriate words – bigger charge (more negative charge). Molecule – should be atom. Uses term from class.
27	I	Ok, you say oxygen has got greater pulling power but what do you mean?	
28	L	Because, erm, it's got more protons so it's got more attraction to the negative electrons, of the negative electrons.	Qualifies meaning of being larger in previous comment.
29	I	The electrons where?	

	30	L	Of the outer shell. END	Appears to have an idea of the notion of “pulling power” but specifies the electrons in the outer shell rather than the bonded pair.

May 2014 - Third attempt at states of matter scenario

Joint interview with Ferne - Language analysis for Linda.

CR	CCL	ICL
3	13	0

Language guidance	Comment number	I = interviewer L = Linda F = Ferne	Transcript	Comments
	1	I	Explain the nature of the water molecule and how it changes as we go from solid liquid to gas.	
	2	F	We are talking about solid liquid gas.	
	3	I	Of the water, yeah.	
Hmm - a sound made when considering something	4	F	So, (drawing diagram) you’ve got oxygen and two hydrogens, which is H_2O, and we have a lone pair of electrons on our oxygen molecule and then there’s some **inter**molecular forces between, I do have to draw really don’t	

Ah – an exclamation.			I? some hydrogen bonds. See I find it much easier to draw it or write it down than to say it sometimes. Hmm, I'm thinking (p2). We've got some **bent** water molecules and we've got intermolecular hydrogen bonds that allow them to form a crystalline structure. In liquid these are further apart and I can't remember, I'm thinking that they've still got hydrogen bonds but they are further apart, I'm going to have to google this. They're moving further apart and the same with the gas and kinetic energy increases which is why, ah! I don't know.	
	5	L	I think as a solid they occupy a bigger space because they are less likely to slide over each other and the hydrogen bonds keep them at a certain distance. Where as in a liquid form, sort of, those bonds continuously break and reattach so it's kind of varying motion driven state. It's in a natural state in a gas it's more spread out and those hydrogen bonds are broken and they move about randomly.	Productive Chemical Interlanguage.
	6	I	How do the hydrogen bonds come about?	
	7	L	Because water is a dipolar molecule meaning that the oxygen is more electronegative and it pulls the electrons from the hydrogen closer which makes it more negative nearer the oxygen and it leaves the hydrogen more exposed because the, on the positive side and attraction between the positive hydrogen and negative oxygen is what creates the hydrogen bond.	Dipolar – possibly acquired from other sources. Usually referred to as polar on the course. Provides a good explanation of using electronegativity in context. Reference to hydrogen being exposed.
			END	

December 2014 - Fourth attempt at states of matter scenario.

Joint interview with Nina - Language analysed for Linda.

CR	CCL	ICL
3	10	1

Language guidance	Comment number	I = interviewer L = Linda N = Nina	Transcript	Comments
	1	I	So why does it go from a gas to liquid?	
	2	N	I don't know.	
	3	I	Do you know Linda?	
	4	L	When there is heat the molecules move more and, er, the heat, er of the, its thermodynamically less favourable, er, so the bonds break because the heat is, the movement requires more energy and they are not able to stay as close to each other and then they evaporate but when they hit the glass then because its colder they move less the molecules stop vibrating as much and sort of once they stop moving they are not moving as much they can reform the hydrogen bonds which happens on the glass so its thermodynamically favourable over thermodynamically unfavourable.	Imprecise use of heat Use of systematic phrase from this term.
			END	

June 2015 - Fifth attempt at states of matter scenario.

CR	CCL	ICL
3	14	0

Language guidance	Comment number	I = Interviewer L = Linda	Transcript	Comments
	1	I	You blow on a Cup of coffee and your glasses steam up, why?	
	2	L	Er, because erm, it's mainly the water molecules like during erm, (p1) when the temperature is high the movement of the molecules is higher whereas the movement of the molecules is lower at the cold temperature. So because the coffee is hot the molecules in the cup move so much some of them actually manage to speed up more than the rest of them because the hydrogen bonds are not strong enough to hold them together and when they reach the glasses because the glasses are cold erm, then the molecules are not moving as much and the hydrogen bonds reform hence the condensation.	Faster and slower would be more appropriate descriptors. Links the movement of the molecules and hydrogen bonding.
	3	I	So when you say they move more less what do they have more or less of?	
	4	L	Kinetic energy.	
	5	I	These hydrogen bonds you mention, what are those?	
	6	L	Er, those are bonds er, between two er, dipolar molecules and they are in water between oxygen and hydrogen because the molecules erm, (p1) charge is not distributed equally so certain parts of them are either more negative or more positive so positive and negative tend to attract to each	

			other whereas if it's er, a nonpolar molecule then those bonds would not exist.	
	7	I	Why is the charge distributed unevenly?	
Ah – an exclamation. In this instance it indicated that Linda was confident about her response.	8	L	Ah, because some molecules they have more pulling power. The bigger molecules they have more pulling power than the lower molecules.	Phrase used in Year 0. Confusing use of molecules Inappropriate comparative – should be smaller.
	9	I	What's the er, the technical term to describe the pulling power effect.	
	10	L	Electronegativity.	
			END	

Appendix 5

Interviews with Linda

Scenario 2 - Amount of Substance.

November 2013 - First attempt at states of matter scenario

Joint interview with Nina **-** Analysis undertaken on Linda's comments.

CR	CCL	ICL
3	3	1

Language guidance	Comment number	I = Interviewer. L = Linda. N = Nina	Comment	Notes
	1	I	Ten grams of lead has fewer atoms in it than ten grams of sodium. Can you explain why that might be the case?	
	2	N	Ten grams...	
	3	I	Ten grams of lead, so I've got a lump of lead, it weighs ten grams.	
	4	N	Yeah	
	5	I	I've got another lump of sodium that weighs ten grams but the lump of lead has fewer atoms in it than the lump of sodium.	

6	L	Will the Periodic Table help?	
7	I	Well, it doesn't really matter, at the end of the day, we've got two substances. Two substances with the same mass but one has fewer atoms. It wouldn't really matter what substance it is. One has fewer atoms than the other one.	
8	N	OK, they can attract each other I think?	
9	I	No, so they're lumps, we've got one lump of something and another lump of something, OK? They both weigh the same but this one has fewer atoms in it than this one (hand gestures).	
10	L	The lead is er, a larger atom and it's a higher atomic mass so the higher the atom the more space they occupy hence less, they are heavier so which means if an atom is heavier er, then it will, for the same weight be less atoms than to make up the same amount of weight. Hence for sodium its atomic mass lighter, one's heavier than the other.	Appropriate comparator. Conflating volume and mass. Using weight rather than mass. More appropriate comparator – "is less" Note absence of "relative" when referring to atomic mass.
11	I	OK.	
12	L	Sometimes it is like we have the right idea of what it is but bringing the knowledge to like, I know what it is I am trying to say but what comes out verbally is different	Linda expresses the difficulties of trying to articulate the understanding she has.

			meaning.	
	13	I	Which is exactly the reason why I am doing these things.	
			END	

May 2014 - Second attempt at Amount of Substance scenario.

CR	CCL	ICL
3	8	3

Language guidance	Comment number	I = Interviewer L = Linda	Comment	Notes
	1	I	I have ten grams of lead and ten grams of sodium but the lead contains fewer atoms than the sodium. Can you explain why?	
	2	L	The, the atomic mass of lead is much is higher than the atomic mass of sodium er molec, molecular, no it is atomic mass and therefore it would take less molecules of lead to achieve the same mass whereas with sodium would need more molecules to achieve the same (p1) actually weight rather than, is mass or weight? What's the difference?	Absence of "relative" i.e relative atomic mass. Identifies atomic mass as the correct term but then refers molecules. Confused as to whether she should be referring to mass or weight.
	3	I	Well yeah...	
	4	L	Same weight, same weight...	

5	I	What's the difference between mass and weight?	
6	L	(p1) The same.	
7	I	The same?	
8	L	Yeah.	Considers mass and weight to be the same.
9	I	If I took ten grams of sodium to the moon would its weight be the same on the moon as it is on Earth?	
10	L	Well no, because in the moon there is no gravity so...	
11	I	There's a bit, but you're right there's not as much.	
12	L	There is a very good bit with Brian Cox about when he lets a cricket ball and a feather and he lets them both fall from height and he measures the speed they are falling and then after there is a vacuum created and he lets them both drop. It is actually quite interesting and they both fall at the same speed.	
23	I	OK, so we didn't quite finish the lead thing, so why are there fewer atoms in the lead than the sodium?	
24	L	Lead's got a molecular mass of about two hundred seventy something which is quite bigger molecules and they're heavier where as sodium is, where was it? Twenty	Now referring to molecular mass.

		something...	
25	I	Very good (laughter). So what does, so you are saying lead is like two hundred and seventy and sodium is twenty odd so what does that mean then in terms of, again it kind of comes back to the ideas in that slide...	
26	L	Yeah, it's er, how many molecules will take to equal to the same amount in grams of carbon twelve isotope which is a measure in molecular units because it's difficult to measure them so it would take less molecules of lead to achieve that weight whereas sodium would need more it will not be equal number to carbon twelve but it will be a little bit less to get the same weight because it's, it's got er, higher atomic weight.	Repeated use of molecules. Referring to weight. Demonstrating conceptual understanding.
27	I	OK, good.	

December 2014 – Discussion of a course slide relating to amount of substance.

Joint interview with Nina - Analysis undertaken on Linda's comments.

CR	CCL	ICL
2	11	5

Language guidance	Comment number	I = Interviewer. L = Linda. N = Nina	Comment	Notes
	1	I	This is one of the slides from one of your lectures and I was wondering if you could explain to me what it is about?	
	2	N	Er, like this is basically about the measurement, the measurement of the weight of the molecule.	
	3	I	OK, so what is this trying to say.	
	4	N	Like (p3) like in one mole of hmm, how do you say that one? (laughter). We know how to calculate everything...	
	5	L	I got this one wrong in the exam...	
	6	N	I'm OK with that one...	
	7	I	OK, so let's try and get some explanation, what is it, what are you trying to calculate?	
	8	N	Like like I calculate all the atomic number, atomic mass I calculate all and then, erm, yeah, atomic mass is equate to	

		gram so I just calculate that one.	
9	I	OK, for what?	
10	N	For each molecule, erm, each molecule.	
11	I	Each molecule. OK, so you work out number of grams...	
12	N	Yeah.	
13	I	Yeah, so that then what? You can weigh out that amount of substance?	
14	N	That amount, yeah.	
15	I	OK, what does the term gram molecular weight mean?	
16	N	Gram molecular weight...	
17	I	Gram molecular weight.	
17	N	Oh, mole. (laughter)	
18	I	Well, isn't that interesting, yeah. What do you think the term gram molecular weight means?	
19	L	It is erm, the amount of, erm, er, number of (p2) grams per molecule in the weight that is equal to, er, the same amount of grams in, erm, of carbon, er, isotope twelve? It's the comparison with so it's erm, how do I explain it now? (p2)	Confused explanation of gram molecular weight. Aware of the relationship to carbon

		Am I close yeah?	twelve but does specify 12g.
20	I	Yeah, yeah.	
21	L	It's atomic weight in relation to carbon twelve isotope. It's atomic weight anyways, the numbers then, it's what we compare.	Atomic weight used rather than relative atomic mass.
22	I	Yeah, OK. Do you recall me using that term last year?	
23	L	No...	
24	I	Gram molecular weight...	
25	L	Not gram molecular we used moles but.	
26	I	Yeah, can you think of a term I used that would be the same as gram molecular weight?	
27	L	Is it Dalton? We didn't use it so...	Refers to word from Year 1.
28	I	Dalton?	
29	L	Yeah.	
30	I	No.	
31	L	You could use moles.	
32	I	So you were just saying equivalent to twelve grams of	

		carbon twelve, this sort of thing. What erm, what sort of words was I using to mean that sort of thing last year?	
33	L	I am trying to work through my brain sorry.	
34	I	No, this is why I am asking. I am really intrigued...	
35	L	Is it molar mass? No it’s not molar mass.	Provides correct response but is not confident.
36	I	Isn’t it?	
37	L	Molar mass.	
38	I	So where on there is a gram molecular weight?	
39	L	(p2) Uh, on the equation you mean?	
40	I	Hmm.	
41	L	Er, it’s er, one...	
42	N	So it is gram molecular weight, it is mass.	
43	I	Hmm.	
44	L	It says one molecule but this would be like one mole then we need to calculate (*unint*). So one moles, two moles, one molecule is worth of one mole so it would be as many, one mole would be equal number of in one gram of carbon twelve, to the carbon twelve yeah.	Considers one mole is equivalent to one gram of carbon twelve.

45	I	So this sentence there this is called the gram molecular weight or mole (p4). Like you said the gram molecular weight, that's a mole. But what's a mole? (Nina laughs).
46	L	It's a unit of measure.
47	N	Yeah, a unit of measure.
48	I	Yeah, well a metre is a unit of measure but I need a bit more than that (laughter). A measure of what?
49	N	No (laughs).
50	L	It's just explaining it rather than er...
51	I	Yeah, so what does the word mole mean?
52	L	Like I said, I know what one mole is but what does it mean...
53	I	What is one mole?
54	N	(laughs) I think, no.
55	L	One mole would have like six point zero twenty two times ten the power of twenty three of carbon mol, carbon twelve molecules in one mole, erm...

56	N	Avogadro number.
57	I	Avogadro’s number, yeah, so one mole is equivalent to Avogadro’s number of what?
58	N	Carbon.
59	I	OK, is it just carbon or?
60	N	Carbon twelve isotope.
61	I	If I have one mole of carbon dioxide what do I have? How much carbon dioxide do I have?
62	N	So we have to calculate molecu, er, atomic mass weight six point zero two two ten to the power twenty three and then we have to calculate (p2) (laughter).
63	I	OK, do you recall the lecture with this slide? Were you following the content of the lecture alright? Can you think back at all?
64	L	I think it is fairly straightforward. Like I said you kind of know it but cannot explain it back within the appropriate definitions. I know the Avogadro’s number we use it quite a lot, unit of mole we use it quite a lot. Erm, and like I said we did this last year so it is basically getting the balance right finding out one way...

65	I	So you say in the exam you got this one wrong, what sort of thing did you have to do in the exam in relation...	
66	L	I think it is very similar it was a bigger molecule of erm, erm, hydrocarbon molecule was a bigger one obviously unlimited oxygen and we needed to calculate how much CO_2 will be produced but what I did I only worked it out for one gram of CO_2. I forgot to increase the number of moles er, to get the appropriate weight. It was me just not being able to focus and go back to it.	
67	I	OK, what does the word stoichiometry mean?	
68	N	It's the (p6).	
69	I	Any idea Linda?	
70	L	It's working out er, how many molecules are needed for a reaction, er. (p2)What it takes for a reaction to be completed so basically to balance both sides of the equation because the number of molecules that go in is the same amount of molecules that need to come out so it's working out how much is used up in the process because we cannot use more or less because there are a limited number, er, I wouldn't know the definition but that is how I would explain it.	Not a clear or concise understanding of stoichiometry.
71	I	Ahmm, OK.	
72	L	So it's just balancing equations, working out how much	

		goes in of each molecule and how much it comes out as different molecules at the other end.	
73	I	Why does he use the terms microscopic and macroscopic there?	
74	L	(p5) Because that's the lecturer (laughter). He likes to stretch. I think he does that on purpose to get everybody to think rather than er, because different people would use different terms and erm, I think he uses microscopic macroscopic just to get a visual of what is happening rather than...	
75	I	So what is that saying to you then there?	
76	L	Two molecules are very small so it is microscopic whereas 2 moles would have more molecules. For instance, two moles, two moles would have er, double, like two times the Avogadro's number.	Shows understanding of the terms microscopic and macroscopic.
77	I	Ahmm	
78	L	So when you calculate it the ratio is huge from one to another.	Partial understanding of ratio.
79	I	Ahmm.	
80	N	I think for me, I think this er, this amount we cannot see with our normal eyes that's why he use microscopic.	

81	I	OK, good.	
		END	

June 2015 - Third attempt of amount of substance scenario

CR	CCL	ICL
2	7	6

Language guidance	Comment number	I = Interviewer. L = Linda. N = Nina	Comment	Notes
	1	I	Ten grams of lead and I have ten grams of sodium but in the lump of lead there are fewer atoms than in the sodium. Can you explain why?	
	2	L	Erm, because the molecules are larger, they have more protons and neutrons er, that's where the weight comes from er, so and they occupy the, they have more electrons which occupy wider space er, and they would require less area to occupy in the same amount of weight than sodium. Actually with the children we have a joke you say like what is heavier one kilo of iron or one kilo of straw? (laughter).	Referring to molecules of the element. Correctly recalls protons and neutrons provide the mass. Appears to be confusing with density. Refers to area rather than volume.
	3	I	Yeah, yeah (laughter). OK, so what sort of thing would we use to describe actually how many atoms or the amount of substance is in that lead?	

4	L	Erm, it's mole.	
5	I	Mole.	
6	L	Or Daltons.	Daltons would not be appropriate to describe amount of substance.
7	I	Yeah, that is something that has come from this year, I remember you mentioning that last time. So Biologists use Daltons but in what sort of sense?	
8	L	I think I find it used more for describing proteins and the size of them.	
9	I	So how would I work out how many moles of lead I have got?	
10	L	(p2) Er, how many moles of lead? Erm, then you would take er, you would need the formula (laughs). Er a mole would be the erm, number, how is it now? The atomic number. Erm, it's basically how many molecules are in comparison to carbon twelve isotope. Erm, I can't explain it properly now, my brain's mashed up but yeah.	Very confused explanation. Refers to atomic number rather than relative atomic mass.
11	I	OK, good.	
12	L	So you have the atomic number and then work out the mass and work out the mole (p2).	
13	I	Good, alright.	

END

Appendix 6

Interviews with Linda

Scenario 3 – Benzene.

February 2014 - First attempt at benzene scenario

CR	CCL	ICL
2	13	0

Language guidance	Comment number	I = Interviewer L = Linda	Transcript	Comments
	1	I	Can you explain why benzene requires a catalyst to react with bromine water whereas cyclohexene and phenol do not?	
Erm – a hesitation.	2	L	Erm, (p1) benzene is a stable molecule because the electrons are spread out all around the ring so it does not react. I think that there are like two er, double bonds. What are they called? Is it pi bonds around the ring?	Aware of the electrons spreading out around the ring but does not use relevant terminology such as delocalised but does refer to pi bonds.
OK - an informal expression of approval or agreement	3	I	OK, good, so how is it different to cyclohexene?	
Er – a hesitation	4	L	Er, well, I have just been looking at this. Cyclohexene is also a ring, a six carbon ring. It does react because it is an alkene and has a carbon double bond.	Shows awareness of the correct meaning of alkene.

5	I	But why does it react?	
6	L	The molecule, erm, (p2) the bromine molecule reacts with the double bond because it is less stable. There is polarity in the bond.	
7	I	What do you mean there is polarity in the bond?	
8	L	It is a bit positive and a bit negative so it reacts.	
9	I	Which bond?	
10	L	Er, the er, carbon (p1), no not the carbon, in the bromine.	
11	I	OK, so why is there polarity in the bromine bond?	
12	L	Because one bromine is positive and one is negative...	Note absence of reference to atoms.
13	I	But why?	
14	L	(p2) I'm not sure.	Unable to explain how polarity in the bromine bond is produced.
15	I	Right, OK so what about phenol?	
16	L	Phenol has an OH on it which destabilises the molecule and means it reacts with the bromine.	Productive Chemical Interlanguage.
17	I	How does it destabilise the molecule?	

	18	L	(p1) Well, er, it is something to do with the electrons on the OH group. (p2) I haven't really learnt this yet.	Unable to explain the effect of the OH group.
	19	I	OK, thanks.	
			END	

May 2014 - Second attempt at Benzene scenario

Joint interview with Ferne - Language analysis undertaken on Linda's comments.

CR	CCL	ICL
3	20	3

Language guidance	Comment number	I = Interviewer. F = Ferne L = Linda	Comment	Notes
	1		Explain why benzene requires a catalyst to react with bromine whereas cyclohexene and phenol do not.	
Ah um	2	L	Ah, benzene is more stable, more stable molecule because the electrons which are, the delocalised electrons sort of move freely but in an organised manner so the polarity is evenly distributed. Whereas this one, I'm not going to try and pronounce it. In this one there is more imbalance because the double bonds, um, the charge is differently spread so the sigma and pi apply slightly differently, so it doesn't need, so if there an electro-phi-lic molecule comes in a reaction is more likely to react whereas with the benzene something needs to initiate the change. I hope I'm explaining it correct. I think that's about it but I still need to	Incorrect word – should be charge. Referring to cyclohexene – lacks confidence to pronounce the name. Applying terms but vaguely

			revise it properly. It's all about distribution of charge.	
	3	I	Anything you want to add to that Ferne?	
	4	F	No (laughter).	
	5	I	What about the phenol.	
	6	L	Does it need a catalyst or doesn't it, I can't remember.	
	7	I	It doesn't need a catalyst. Benzene does but phenol doesn't.	
	8	L	The OH group itself is sort of slightly destabilises the molecule because it is a negative, no it's got two, a dipolar molecule in terms of the OH if its attached to the ring it will cause imbalance among the electron distribution.	"dipolar" not a term used in class (polar)
Erm – an interjection used commonly to fill awkward space in conversations.	9	F	It activates the, sorry I was just thinking. It activates the (p1) delocalised, what is the benzene ring , this erm, what's it called these electrons. The lone pair of electrons activates this ring therefore it, erm, this becomes involved, see I'm kind of getting there but not using the right terminology, uh, I'm not putting a curly arrow right. I am just saying that is involved here but then you get this kind of thing. Is it the electron cloud so these electrons and these electrons here react together and then that's where I stop, sorry.	
	10	I	But why does that mean that I can put bromine water with this one and it will react compared to this one when it won't?	

	11	F	Is it because these electrons are moving over to this area as well as these ones moving over these areas. I've revised it but I still can't remember it all. Is it because the distribution of the-electrons will induce a…	
	12	I	Induce what?	
	13	F	A dipole on the bromine.	
	14	L	Different molecules and different, er, atoms have a different electronegativity. So if it needs to be above a certain level or below a certain level so if it's bromine is more electronegative so it is more likely to react than if it's something less electronegative.	Refers to molecules having different electronegativity. Very confused usage of electronegativity.
	15	I	So with that bromine molecule there Br and Br is the electronegativity irrelevant or significant?	
Yeah – informal word for yes.	16	L	Yeah, because they are bigger electrophiles than the OH – something to do with how strong electrophils they are. Which card trumps which card.	Comparing bromine molecule and OH as electrophiles. Understanding of the mechanism incorrect but appears to be using an appropriate term for her explanation. Uses more appropriate word (strong) on the second occasion.
Me - my	17	F	I am just getting a bit confused about me positive and negative because I know that these electrons here are going to go here but I can't remember which ones. If those electrons there will it be delta negative, delta positive?	

	18	L	I think the positive is on top because the pi bond is negative and pi would attract positive.	Unsophisticated use of language (pi bond is a region of higher electron density)
	19	F	Yeah but then why, is that right then or not.	
	20	I	Ferne is circling a lone pair of electrons on the bromine atom.	
	21	L	I think you are over complicating it now.	
	22	I	Why do you think she is over complicating it?	
Kind a – kind of	23	L	Pair of electrons here but you don't really need it. Otherwise, you kind a when you write it, it might get confusing. The line itself implies its double electrons. The question is why does it react not how does it react.	
	24	F	I think you need both.	
	25	I	Why did it then?	
	26	L	Because bromine is a <u>stronger electrophil than the OH group itself</u> and so it will take over its place and become neutral…	Referring to comparing the two species as electrophiles and a substitution occurring.
Went off on one – phrase used to refer to when someone starts to drift away from the point.	27	I	Now you see, that isn't the reason. It's a really interesting answer. There was a bit you said about inducing a dipole and then you went off on one a bit here.	
	28	L	This one's positive and this one's negative and then it will kick	Describing the wrong mechanism.

		out the hydrogen, actually the oxygen will stay here, right?	
29	I	Well, now you're quite hung up on this but no reaction happens here.	
30	F	This lone pair of electrons just activates the ring. Which is why you don't need the catalyst.	
31	I	That's right.	
32	L	Because it is three different rings they are all slightly different so it is understanding the difference from one to another. Ok so where would the bromine join?	
33	I	On to here.	
34	F	So, (p2) I need to get this straight in my head, electrophilic, nucleophilic.	
35	L	Actually it's much more simple than electrophilic at the moment. Is that correct?	Meaning unclear.
36	I	Well electrophiles is what we have focussed on.	
37	L	You remember bits and I remember bits.	

June 2015 - Third attempt at benzene scenario

CR	CCL	ICL
2	5	6

Language guidance	Comment number	I = Interviewer L = Linda	Transcript	Comments
	1	I	Why does phenol and cyclohexene readily react with bromine water when benzene does not.	
	2	L	Benzene is more stable than the phenol because er, it has a, I think side functional group and benzene has a, actually I've forgotten it. Erm, yes I think that's it. It's more reactive, more unstable whereas the benzene's got dislocated electrons which erm give it stability the way they are positioned.	Incorrect term – dislocated instead of delocalised.
	3	I	So when you say the phenol has got a side group any idea how that has a destabilising effect?	
Gonna – going to	4	L	Er, it's an OH group which erm, it's more electronegative and it's gonna pull the electrons, it's gonna drag the electrons more er and hence it's being more reactive with the other species.	Unclear use of electronegative – appears to referring to the OH group. Suggesting reactivity is increased by dragging the electrons.
	5	I	OK so when the phenol reacts it's the OH group that reacts with the bromine in bromine water?	

6	L	Er, yes, whereas the benzene is more evenly spread out so it doesn't have er, erm, areas where there is more.	Thinks that the OH group reacts with the bromine water.
7	I	OK, when you say it is more evenly spread out what do you mean?	
8	L	Erm, it's evenly spread out, it's the electrons er, the magnetic field. No it's not even a magnetic field. How can I explain it, the electronegativity is evenly spread out and then there are no unstable whereas like OH group pulls, like makes it more, one side more electronegative than the other side of the ring making it more reactive.	Electronegativity used incorrectly.
9	I	What effect does it have on the bromine molecule?	
10	L	I think the bromine molecule will, er, bind with one of the carbon atoms. Bromine will kind of stabilise because it's a reactive element molecule it will bind with one of the er, carbons and form a new molecule.	Bind used rather than bond. Inappropriate word.
11	I	OK, so not with the OH group then?	
12	L	Erm see I can sort of see it in my head but not clearly enough. Er, no I'm not sure, I can't remember. I think it might be with the OH group and then we end up with an available proton whereas the bromine connect. I can't remember I'm sorry.	Unable to recall the mechanism.
13	I	No, no, that's fine. What about the cyclohexene can you remember?	
14	L	I think it is more stable, er, it doesn't have a functional group.	
15	I	So does the ene part of the name as in cyclohexene mean anything to you?	

16	L	Erm, it is the same group, alkali, no sorry can't remember. I am visual learner but can't really recall.	Incorrect term – alkali instead of alkene.
17	I	OK, thank you.	
		END	

Appendix 7

Interviews with Evan

Scenario 1 - states of matter

November 2013 - First attempt at states of matter scenario

CR	CCL	ICL
3	8	1

Language guidance	Comment number	I = Interviewer E = Evan	Comment	Comments
	1	I	I have a cup of hot coffee and I blow on it and my glasses steam up, OK?	
	2	E	Yep.	
	3	I	Can you explain why?	
Er – hesitation *Is in the* – correct to *has a* *Will be* – correct to *will* *In* – correct to *on*	4	E	I think, first of all, according to kinetic theory of kinetic energy er, the water, the coffee is in the high temperature and when we blow the coffee you give the energy to the vapour, vapour water and the vapour water will be vibrate vibrate around and er, move quickly and it will be, and it will be quickly moved to your, to your glasses and when the vapour, vapour water move er, in your glasses it's in a high, it's in a low temperature and the, the vapour, vapour water will be cool down, become a liquid of the water.	Suggests blowing imparts energy to the "vapour water" Idea of vibrating but does not mention molecules. Evan regularly repeats part of the sentence as if to check himself and continues if he feels it is correct.

OK - an informal expression of approval or agreement	5	I	OK, thank you. END	

March 2014 - Second attempt at states of matter scenario

CR	CCL	ICL
3	17	1

Language guidance	Comment number	I = Interviewer E = Evan	Comment	Comments
	1	I	I breathe on the coffee cup, my glasses steam up, can you explain why?	
Erm - a hesitation *Hss* – a sound made by drawing air in between the teeth, represents a hesitation. *Make change* – correct to *change*	2	E	I think first er, you blow and er, the blowing can er, can give the kinetic energy to the, hss, to the coffee and the water in the coffee can evaporate and erm, evaporate and it will become er, it will it can energy er, making energy transfer er, to change from the, hss, liquid to the gas and the gas will evaporate and the evap the evaporation will reach reach your glass er, reach your glasses and erm, absolutely the glasses is cool and the evaporation will give their heat energy to become the, to transfer the heat energy to the glasses and and the temperature will cool down and they make change from the gas to a liquid.	Refers to blowing imparting energy. Often repeats words in sentences. Using evaporation as a noun – really referring to the gaseous molecules.

3	I	Alright, so it’s quite a lot of technical words you are using there…	
4	E	It’s like the condenser.	
5	I	Yeah, it is. So, thinking of the molecules, themselves, does anything change about them?	
6	E	Change about them?	
7	I	Yeah, so as the water turns from a gas to a liquid what are the actual molecules doing?	
8	E	Ah, OK, I think that as they change from gas to liquid they come closer to each other and they lose kinetic energy.	
9	I	Yes, but is there anything attracting the molecules together?	
10	E	Attracting, like a force?	
11	I	Yes.	
12	E	So, there is force between the molecules, erm. What is it called? I think it is inter intermolecular force.	Recalls relevant terminology.
13	I	Good, do you know the name of the intermolecular force?	
14	E	Erm, hss (p2) hydrogen bond?	Indentifies correct force.
15	I	That’s right, are these found in the liquid and the gas?	

	16	E	It is not in the gas because because they are far apart, just in the liquid.	
	17	I	And how do the hydrogen bonds form?	
Attract – correct to *attracted*	18	E	(p3) The water molecule is er is a bit negative and a bit positive. The the oxygen is negative I think? And the hydrogen is positive. And they are attract to each other from the molecules.	
	19	I	Why is the oxygen a bit negative?	
	20	E	Er, erm, (p2) it has more electron, erm. Sorry, no I can't explain it.	Unable to explain polarity.
	21	I	OK, thank you.	
			END	

December 2014 - Third attempt at states of matter scenario

CR	CCL	ICL
3	23	4

Language guidance	Comment number	I = Interviewer E = Evan	Comment	Comments
	1	I	I have a cup of coffee and I blow on it and my glasses steam up. Can you explain why?	

Make – correct to *makes* *Is* – correct to *are* *Change* – correct to *changes*	2	E	Erm, (p1) erm, first we (p1) er, we blow, we blow wind in the coffee and hss, (p1) and the and the force from, from our mouth will bring, will bring kinetic energy from you to, to the coffee and make the make the molecular or water molecular or some molecular in the coffee evap er, er, evaporate and (p1) um, and the liquid of the water er, can er, and this energy will hss, and will um (p1) er, we transfer I think we transfer this energy kinetic energy to er, to the external energy? from from you from you to the er, hss, to the coffee and this energy make er, make the coffee evaporate and evaporate and make the make the vapour so the vapour from vapour from coffee can rise up and to your glasses the glasses and when it's when it's on your glasses your glasses is cool and the cof coffee will cool down and then it change from a vapour to a liquid again.	Uses adjective molecular instead of noun form molecule. States that energy from blowing will provide molecules with the energy to evaporate. Regularly repeats phrases
	3	I	OK, so what's actually happening in terms of the water molecules when that happens? So you say they cool down and the vapour turns to a liquid on my glasses, what's actually happening in terms of the water molecules to do that?	
	4	E	Erm, (p1) it will have a more fixed structure, I think and from the vapour to to wat from vapour to liquid will have a fixed structure.	Corrects water to use liquid instead as a more appropriate word. Refers to a liquid as having a fixed structure
	5	I	And specifically with the water molecules what is happening to create that more fixed structure?	
	6	E	Erm, they are in a different phase I think and the phase the phase in liquid should have a more fixed structure than gas one.	Phase – more sophisticated word choice.
	7	I	But what is holding the water molecules together?	

8	E	Erm, Van der is it Van der Waal is it the van der Waals' force?	Incorrect intermolecular force.
9	I	What's a van der Waals' force?	
10	E	(p3) van der Waals' force is between different molecules (p3). I have no idea.	Lack of confidence in response.
11	I	OK, can you draw a water molecule? What would you draw if you were going to draw a water molecule? Is there anything you could add to that? I am thinking in terms of showing its interactions with other water molecules. (drawing) So why have you drawn that dashed line…	
12	E	Er, it's hydrogen bond.	Recalls correct intermolecular force
13	I	OK and what sort of thing is hydrogen bond?	
14	E	Erm (p2), I think it's a struc special bond (unint)	Vague term.
15	I	OK, why does it form between that O and that H like that?	
16	E	Umm, it's a dipole dipole and hss, erm (p2) and dative bonds yea, no?	Appears not to understand the meaning of dative bonds
17	I	So is there anything you could add to that water molecule to indicate why that hydrogen bond forms?	
18	E	OK (drawing)	
19	I	OK, so why have we got a delta minus on the oxygen and delta plus on the hydrogen?	

20	E	Umm, (p2) is it about (p1) I think it's about the atom orbital. I need to draw it. Er, we got one lone pair in er, in oxygen and this lone this lone pair will repel (p1) have a repulsion.	Should be atomic orbital. Appears to be confusing the establishment of a dipole with molecular geometry.
21	I	Repulsion? Is that what you are saying?	
22	E	Erm, have a repulsion er, and this lone pair will become the delta minus, yeah.	
23	I	Alright, is there any other reason why oxygen is delta negative?	
24	E	Umm.	Does not appear to be aware of the importance of electronegativity.
25	I	In terms of between the O and the H and by that I mean the hydrogens on the actual molecule. Is there any, anything important there? (p5) What about if I said the word electronegativity? Does that have any relevance to that molecule?	
26	E	Umm, yes I think oxygen is more electronegativity than the hydrogen.	Repeats noun form rather than using adjective - electronegative
27	I	So what effect would that have?	
28	E	Er, I think it's electrocentre will er, draw from the hydrogen to more close to the oxygen.	New terminology from year 1 Demonstrates an understanding of the effect of the electronegativity

				difference.
	29	I	OK so what effect will that have therefore, on the charge on the oxygen? If those electrons are being drawn more to the oxygen?	
	30	E	So will cause the cause it this side will have more hss, er, electron density and cause and induce that become delta minus.	Corrects *cause* to *induce.*
	31	I	OK	
	32	E	Electron density – I forgot it. (laughter)	
			END	

June 2015 - Fourth attempt at states of matter scenario

CR	CCL	ICL
3	9	5

Language guidance	Comment number	I = Interviewer E = Evan	Comment	Comments
	1	I	I have a cup of coffee, I blow on it and the steam it forms condensation on my glasses, can you explain why?	
Is – singular used rather than plural – are.	2	E	Erm, I forgot the answer (laughter). I want to explain, I want to say erm, you blow and you give kinetic energy to the coffee and make the coffee er, in the coffee it will evaporate and transfer kinetic energy to the coffee and the coffee, the matter in the coffee got the kinetic energy and they evaporate and er, when the coffee matter evaporate they er, they they, expand in the air and they will reach your glasses, when they reach your glasses and and er, the glasses is, the	Refers again to blowing imparting kinetic energy to the molecules to cause evaporation. Unusual use of matter rather

is this – correct to *"is"*			temperature of the glasses is this lower than the coffee and er the coffee will convert it into the glasses and they cool down and they become they change from the er, gas state to the liquid state and make like drops on your glasses.	than particles / molecules.
	3	I	OK, so you say when we blow on the coffee it gives the molecules kinetic energy so it's the energy from my blowing that gives the molecules the kinetic energy?	
	4	E	Yes.	
	5	I	Yeah, so what about, so even if I didn't blow on the coffee, you know, I just kind a hold it here would I still get condensation?	
	6	E	Alright, so I think umm, it's about convention? ~~The coffee is very is hot and it~~ will convention the heat to the air, to the atmosphere so I think the rest of that is (unint).	Means convection
	7	I	So when you say like the coffee is hot and the molecules…	
	8	E	It's convention or convection?	Realises mistake and checks word.
	10	I	Convection.	
	11	E	Convection (laughter).	
	12	I	Convention is more like a meeting such as a scientific convention, a conference.	

Word – singular used instead of plural - words	13	E	The word are similar like convection and er…	
	14	I	Conduction?	
	15	E	Conduction ah yes.	
	16	I	Conduction is direct transfer of heat so like me touching that and heat would directly…	
	17	E	Alright,	
	18	I	Convection currents so like in the hot coffee you've got warm air rising, you're getting a current forming there.	
	19	E	Conduction and convection OK.	
	20	I	So, what does heat energy mean? What does the fact that they are hot actually mean?	
	21	E	Heat energy, I think it mean internal energy erm, heat energy (quiet)	
	22	I	So you say, you know, the temperature is higher, they are hot. What does that actually mean?	
	23	E	Heat energy I think it mean umm, internal energy hss, its internal external energy in the of the coffee hss.	Appears unable to relate temperature to molecular vibration.
	24	I	But what I mean is on a molecular level so what does it mean in terms of molecules, heat energy? So if we say something is hot it's got a lot of heat	

		energy what does that mean in terms of molecules, compared to something that is cold?	
25	E	Potential energy? Hss, potential.	Uncertain of the term to use
26	I	What is different about the molecules?	
27	E	Erm, it's not free energy Gibbs free energy, not, entropy? No. Enthalpy, enthalpy?	Thinking through different terms and decides on enthalpy.
28	I	Yeah, so er, enthalpy is of heat energy but erm, what are the molecules doing when they're hot compared to when they are cold?	
29	E	Oh, I can't remember (laughter).	
30	I	Well, I mean why do they turn from a liquid to a gas? You said in terms of them having more of kinetic energy didn't you?	
31	E	Yes.	
32	I	Yeah, so what must that mean about something that is hotter compared to something that is colder?	
33	E	Erm, hss, (p3) there's not word in my mind (laughter).	Does not think of molecular vibration.
34	I	OK, the point is that it is a measure of molecular movement isn't it? So the hotter they are the more vibration you've got so that heat energy is a measure of how much the molecules and atoms are vibrating.	
		END	

Appendix 8

Interviews with Evan

Scenario 2 - Amount of substance

November 2013 - First attempt at amount of substance scenario

CR	CCL	ICL
2	10	1

Language guidance	Comment number	I = Interviewer E = Evan	Comment	Comments
	1	I	One gram of sodium has more atoms in it than one gram of lead. Can you explain why?	
Only can – can only.	2	E	Er, I c, only can use simple explanations. Because relative atom mass for the sodium is hi, is bigger than that of the lead.	Uses atom rather than atomic. Relative atomic masses are the wrong way round. Changes choice of comparator from higher to bigger.
	3	I	The relative atomic mass for sodium is bigger than for the lead?	
How much mole – how many moles.	4	E	Yeah, relative relative so when we calculate er, one gram we use mass to divided by er divided by Ar atom atom, relative atom mass and we can calculate how much mole of it so use this calculation we, we can conclude the	Use of symbolic language.

The mole of the – the number of moles of.			(p1) we can conclude the ma, sorry, hss, the mole of the sodium is larger is bigger, is mor, is more than that of the lead.	Changes choice of comparator from larger to bigger to more than.
	5	I	Right, OK.	
	6	E	I think something, is it because, er, is it because the structure of the atom and can only can explain it because atom, atomic number of the sodium is smaller than that of the lead and er, it will, it will er, deduce, we can deduce it, the number of protons and electrons and this is we can and when we add the proton and elec, er, proton and neutron, neutron, it can, we can k now the mass, the relative mass er, relative atom mass of different atom er, elements so, hss, we can only, we can also use the formula to calculate.	
	7	I	Excellent thank you.	
			END	

December 2014 - Second attempt at amount of substance scenario

CR	CCL	ICL
2	5	2

Language guidance	Comment number	I = Interviewer E = Evan	Comment	Comments
	1	I	I have ten grams of lead and I have ten grams of sodium but the ten grams of lead has fewer atoms in it than the ten grams of sodium. Can you explain why?	

But we saying – but we are saying.	2	E	Erm, (p8) it's because, it's we can simply say it's different from the relative molecular mass and then may have the bigger molecular mass, relative molecular mass and we use, we use the formula to to calculate it will have the more molecular but we saying the microscopic and lead will have, no that is about the density. (p5) This is the way to explain it.	Incorrect molecular – molecules. Recognises that density is a different concept.
	3	I	OK, so what, the relative molecular mass of lead compared to sodium is what?	
	4	E	Er, the lead is bigger than the sodium.	Not the most appropriate comparator – higher.
	5	I	OK, OK. Is relative molecular mass the right term when talking about lead and sodium?	
	6	E	(p2) Sorry.	
	7	I	What does the word molecule mean?	
	8	E	Molecule (p4), molecule mean, (laughter) it mean the (p2) molecule, Er (p2) nucleus (p6) have one er, have a...	Struggling to explain the meaning of "molecule".
	9	I	What's the difference between an atom and a molecule?	
Is to have atom – is atoms.	10	E	Atom and molecule, oh molecule it mean er, it can consis, consist of er, different number of er, atoms. Hss, I think lead is to have the atom not the molecule and I think sodium as well.	Uses different number rather than different type of atoms.
	11	I	So what would be a better term than relative molecular mass?	
	12	E	Er, er, relative atom mass yeah.	Still uses atom instead of

				atomic.
	13	I	What's the difference between molecule and molecular?	
	14	E	Er, molecular is the A D J.	Refers to adj rather than adjective.
	15	I	Adjective.	
	16	E	Adjective and molecule is the, is the noun.	Aware of the difference between molecule and molecular.
	17	I	Alright, brilliant.	
			END	

June 2015 - Third attempt at amount of substance scenario

CR	CCL	ICL
2	11	2

Language guidance	Comment number	I = Interviewer E = Evan	Comment	Comments
	1	I	I have ten grams of lead and I have ten grams of sodium but there are fewer atoms in the ten grams of lead than the ten grams of sodium. Why would that be the case?	
	2	E	And compare for what sorry?	
	3	I	So the number of atoms in the ten grams of lead is fewer than the ten grams of sodium...	

	4	E	Oh yeah, it's just about molecular mass. We need, it's like a formula erm, erm, the mole of the substance equal to the mass divided by molar mass and it's about just this I think.	Refers to molecular mass rather than atomic mass.
	5	I	Yeah, OK, so how could I express the number of atoms that's in either of those substances...	
Hss – a sound representing a pause.	6	E	Oh right, I know what you mean. It mean, hss, I think er, I think for the lead the atom is, hss, the radius of atom is big and maybe they occupy more space. Therefore, for the sodium, they occupy less space.	Starts talking about the space that the atoms occupy.
	7	I	OK but so how can I say, so in this ten grams of lead I have this amount of substance? How would I actually say the amount of substance? i.e. the number of atoms I have got in that? What sort of language would I use to describe that?	
	8	E	Erm, molar mass is, molar mass equal to the mass of the total nucleus, hss, of the total neutron er nucleus yeah nucleus. It's about the neutron and the, hss, proton and about the electron yeah. And so for these they have more nucleus than the sodium so the bigger the molar mass and...	Considers electrons important for the mass. Incorrect comparator - larger
	10	I	Yeah, so how could I convert from saying ten grams to saying actually how many are there? How would I express those ten grams as an amount of substance? As a number of atoms?	
	11	E	Oh, the atoms, oh we, hss, first we use the formula. The molar mass equal to	Very unclear explanation.

the er, mass divided by er sorry the mole of the substance divided by it then we use Avogadro's number.

12 I Right, OK.

END

Appendix 9

Interviews with Neil

Scenario 1 - States of Matter.

November 2012 - First attempt at states of matter scenario

CR	CCL	ICL
3	7	0

Language guidance	Comment	I = Interviewer N = Neil	Transcript	Comments
	1	I	I have a cup of tea, I breathe on it and my glasses steam up. Can you explain what's happening there?	
Er – a hesitation	2	N	Er, When your breath hits the surface of the liquid it cools the surface of the liquid which gives off more steam back towards you. It like, the airflow pushes it out faster erm, which then condenses on the glasses because the gases are obviously cold compared to the gas which is released.	
	3	I	OK, so when you say it is cold, for that condensation to form on the glass what is actually happening?	
Erm – a hesitation	4	N	Erm, When the gas, which has a large amount of kinetic energy, hits the glass it stops moving quite as, the particles stop moving quite as fast and it forms a liquid on the front of the glasses.	Shows awareness of kinetic energy and molecular movement.
	5	I	OK and in terms of the water molecules themselves, does anything change about them?	

Language guidance	Comment	I = Interviewer N = Neil	Transcript	Comments
	6	N	How do you mean?	
	7	I	Well, when the water goes from gas to liquid on the glasses what are the actual molecules doing?	
Ah – an exclamation	8	N	Ah, OK so as a gas they far apart but when they become a liquid they are closer together.	
	9	I	Yeah, is there anything attracting the molecules to each other?	
	10	N	Erm, er, I don't know a bond or something?	Unaware and unable to explain the interactions between molecules
	11	I	OK, thank you.	
			END	

May 2013 - Second attempt at states of matter scenario

CR	CCL	ICL
4	16	0

Language guidance	Comment	I = Interviewer N = Neil	Transcript	Comments
	1	I	After a cold night condensation forms on the inside of a window pane.	

2	N	The condensation forms due to the warm air which has moisture in it coming into contact with the cold glass and the moisture in the air is cooled rapidly which results in droplets of water forming on the glass.	Uses scientifically academic words.
3	I	OK, so can we take any, like more microscopically if you like. So you say the moisture cools.	
4	N	The kinetic energy decreases rapidly.	
5	I	Of what?	
6	N	Of the molecules of water as it comes into contact with the cold window.	
7	I	OK and what about in terms of the water molecules themselves...	
8	N	So as a gas they are far apart, moving randomly and then when become liquid they are closer together but moving over each other.	
9	I	Is there anything attracting the water molecules to each other?	
10	N	Er, hydrogen bonding?	Able to name the intermolecular force.
11	I	Yeah and what is hydrogen bonding?	
12	N	There is a dipole in the molecule erm, you've got the oxygen and the hydrogen and the oxygen is a bit negative and the hydrogen is a bit positive.	Appropriate use of dipole.
13	I	Why is the oxygen a bit negative?	
14	N	Because the (p1) electrons are more around the oxygen atom.	Good use of atom.

	15	I	Why are they more around the oxygen atom?	
	16	N	Because they are attracted more to the oxygen?	
	17	I	Yes, but why are they?	
	18	N	Erm, well it's oh what is it? Hmm, I'm not sure.	Unable to provide an explanation involving electronegativity.
	19	I	OK, thank you	
			END	

February 2014 – Third attempt at states of matter scenario

CR	CCL	ICL
3	15	3

Language guidance	Comment	I = Interviewer N = Neil	Transcript	Comments
	1	I	I have a cup of coffee, I blow on the coffee and steam forms on my glasses. Explain why that is the case.	

2	N	I knew you were going to ask this one (laughter). So you blow on the coffee, er, which is hot erm, as the cold oxygen molecules and (p1) not sure should they be molecules? It is O_2 so it's molecules. So the molecules in air, you are going to have oxygen, CO_2 erm, make contact with the hot surface erm, heats it very rapidly and releases steam. the steam connects with your glasses, cools very rapidly and forms condensation in the process.	Good awareness of the meaning molecule. Interchanges between word and symbolic chemical names.
3	I	OK so when you say things are heating up and cooling down what specifically, you know, does that mean in terms of the molecules of the coffee of the water? What's changing about them?	
4	N	Erm, they become less active when they are cooling down or more active when they are heating up.	Interesting use of the word active rather than vibrate for example
5	I	So what do you mean by less or more active?	
6	N	They lose kinetic energy or gain kinetic energy.	
7	I	And then thinking more specifically as water molecules, what's changing about the interaction of those water molecules as they go from liquid water to steam or vice versa?	
8	N	Erm, they lose the attraction of the van der Waals' forces when they become steam. They're more active, they spread out further, they're not as attached to each other. When they cool down the van der Waals' forces take back over. Staples it together to form a liquid.	*Staples* – Unproductive Chemical Lanaguage
9	I	What's a van der Waal force?	

10	N	It's the (p2) it's the force between the hydrogen (p1) ions (p1) because they've only got one electron each and they like to share the *energy from the ions* (unintelligible). Am I anywhere near?	
11	I	That's really interesting and um, well let's um, can sketch like what a water molecule is like at all? Any idea what it would look like?	
12	N	Erm, H two O, just thinking erm, hydrogen is an H+ ion, they are going to have two but they want, I'm trying to think.	Correct use of language in relation to his previous statement.
13	I	So there we have got water H two O.	
14	N	Yeah.	
15	I	But what is happening between the hydrogen and the oxygen to form that molecule?	
16	N	The hydrogen's giving the oxygen their electron so the van der Waals forces are just forces between the hydrogen atoms.	Quieter speaking reflecting a lack of confidence in the response. Confusing response.
17	I	Well let's explore the molecule a bit more so the hydrogen is giving an electron to the oxygen but is the oxygen doing anything.	
18	N	I suppose it will be giving one back to each other so they each have two.	
19	I	So what sort of bond forms between the oxygen and the hydrogen?	
20	N	The word is on the tip of my tongue (laughter). (p3)	

21	I	Basically they are sharing that pair of electrons.	
22	N	Yeah.	
23	I	What sort of bond was it when they are sharing electrons? This is mean isn't it? (laughter)	
24	N	It's not mean, it's quite interesting, these things get so pushed to the back of your mind and yet I sought of feel like it is on the tip of my tongue.	Unable to remember the name of the type of bond.
25	I	Yeah, yeah, it's like in a pub quiz or something isn't it? So a covalent bond...	
26	N	Covalent bond...	
27	I	Between these two...	
28	N	I am thinking it begins with a C, is it compound...	
29	I	Excellent, OK, so we get a covalent bond from between the oxygen and the hydrogen so does anything happen in terms of that covalent bond. (p2) so they are sharing that pair of electrons (p2) are they sharing that pair evenly?	
30	N	No, the electrons switch from side to side don't they? They move (p1) and the force pulling them alternates.	Confusing statement – perhaps confusing with temporary dipoles,
31	I	Have you any idea why something like that happens or why there is isn't an even distribution?	
32	N	(p4) I remember the action I can see it but I can't remember why it does it.	

	33	I	So what can you see in your mind now?	
	34	N	I just see the electrons sort of going around the (p1). Is that what creates the van der Waals' force then?	
	35	I	Well, that's where we are leaning to, what is a Van der Waal force? So we do end up with an uneven spread of the electrons so the electrons spend more time around the oxygen than the hydrogen.	
	36	N	Yeah.	
	37	I	There is a term for that, (p1) why the oxygen attracts the electrons more than the hydrogen and I would be surprised actually if this is a term that you would use at all now (p2) Electronegativity? Does that ring any bells?	
	38	N	It rings a bell now you say it but again I would never have...	Unable to recall electronegativity.
Gonna – going to.	39	I	Yeah, so the oxygen is more electronegative than the hydrogen so if the electrons are spending more time around the oxygen, what's gonna happen to that oxygen atom compared to the hydrogen atom if that pair of electrons are spending more time around the oxygen?	
	40	N	The oxygen is going to become more positively charged.	
	41	I	It's got the electrons...	
	42	N	Oh, The electron's negatively charged.	Realises the mistake.
	43	I	Right, OK, we end up with a bit of a negative and a bit of a positive...	

44	N	And a bit of a positive and it's that slight positive force on the hydrogen atoms.	*Force* used instead of *charge*
45	I	(p1) so then, yeah, what happens then?	
46	N	Oh god not that symbol (laughter).	Strong response to use of symbolic language of delta symbol.
47	I	So what is that symbol?	
48	N	I can't remember but I remember seeing it. I remember it being written down numerous times (laughter). I probably understood it perfectly at the time because I didn't mind drawing stuff out like that, that was the easy bit.	
49	I	So the delta negative and delta positive? So delta, is that a term used medically at all? Is that a symbol used for things at all?	
50	N	Delta not so much, alpha and beta very much. I feel like delta came up in first year at some point but I can't remember where.	
51	I	OK, so we've got these partial charges but what is going to happen if another water molecule comes along side that?	
52	N	Erm, (p1) in that sense the attraction between the hydrogen of this one and the oxygen of another one I suppose because you are going to have the positive and negative erm, vice versa.	
53	I	Good, so is that a van der Waals' force?	

54	N	I'm guessing so? but I genuinely did not remember that.	Does not recognise the nature of the different types of intermolecular forces.
55	I	Yeah, well it's not quite a van der Waals' force, because what we have here is what's called a permanent dipole, permanent charge difference whereas the van der Waal force happens temporarily?	
56	N	Yeah.	
57	I	I don't know if you remember the likes of iodine and chlorine where you've got basically the same atoms and you just get a temporary shift in electrons and **then** you get this van der Waal force.	
58	N	Yeah.	
59	I	And all your hydrocarbons that's what they have attracting between them but here we have a specific type of called permanent dipole, permanent attraction between them. Can you remember what that is? This might have been a term, because obviously water is so fundamentally important it might well've been the sort of thing, do you talk about drug interactions at all? Very important in that sense, cells as well.	
60	N	We don't cover it in that much detail. It's never come up that particular force of attraction, we don't do a lot of detail on drugs. I'd imagine Pharmacy do that a lot.	Unable to recall electronegativity.
61	I	So if I said hydrogen bonding is that a term you kind of haven't come across in recent years?	
62	N	No, not something we've done in medicine specifically. I also remember	Terms not used in

		hydrogen bonding vaguely from when we were doing it at foundation but no. When we're talking about medicines it is usually the effect they have, what do they do to the cell?	undergraduate course.
63	I	But you don't look on a molecular level why it has that effect, so in terms of the chemical structure of a drug and how it is interacting with a cell membrane like that?	
64	N	No not really, no.	
		END	

Appendix 10

Interviews with Neil

Scenario 2 - Amount of Substance.

November 2012 - First attempt at amount of substance scenario

CR	CCL	ICL
3	2	1

Language guidance	Comment	I = Interviewer N = Neil	Transcript	Comments
	1	I	Ten grams of lead has fewer atoms in it than ten grams of sodium. Can you explain why that would be the case?	
	2	N	In that case it would be due to the, how condensed the particles or the atoms are within the substance. So in the lead the atoms would be further apart and there would be less of them than there are in 10 grams of sodium.	Unusual use of condensed in this context. Suggests linking to kinetic theory and states of matter. Incorporating ideas of density.
OK - an informal expression of agreement	3	I	OK and anything about like the size of the atoms or anything like that? So you said they were further apart or closer but is there any difference in the size of lead atoms compared to sodium atoms?	
	4	N	Erm, the lead atoms would be a larger size than the sodium atoms.	States the lead atoms are larger but makes no specific reference to mass.

	5	I	OK. Thank you. END	

May 2013 - Second attempt at amount of substance scenario

CR	CCL	ICL
3	2	1

Language guidance	Comment	I = Interviewer N = Neil	Transcript	Comments
	1	I	Ten grams of lead has fewer atoms in it than ten grams of sodium. Can you explain why that would be the case?	
	2	N	(p8) Sodium atoms are heavier than the lead atoms because they have a higher proton and neutron content.	Heavier relates more to weight rather than a greater mass. Uses concept of some atoms being heavier than others and relates to differences in atomic structure.
	3	I	So ten grams of lead has fewer atoms in it than ten grams of sodium.	
	4	N	(p3) Sorry, it's the other way round. Lead is heavier, sorry, than sodium. The gol, gold has more protons and neutrons than lithium.	After prompting realises that lead is "heavier" than sodium.

	5	I	OK, so, what expression could be used to say that?	
	6	N	(p2) It has a (p4) I don’t know to be honest. I honestly don’t know.	Unable to develop an explanation using relative atomic mass or moles.
	7	I	OK.	
			END	

February 2014 - Third attempt at amount of substance scenario

CR	CCL	ICL
3	5	0

Language guidance	Comment	I = Interviewer N = Neil	Transcript	Comments
	1	I	Ten grams of lead has fewer atoms in it than ten grams of sodium. Can you explain why that would be the case?	
	2	N	Atomic mass isn’t it? So the atomic mass of one is smaller than the other.	Omits relative.
	3	I	OK, so like the ten grams of lead has fewer atoms in it than ten grams of sodium which one of those would have the larger atomic mass?	
	4	N	The lead.	
	5	I	The lead, OK. And is there a way I could like, come up with a calculation that would kind of express how many atoms are there?	

	6	N	The mole mass equation but I can't remember the equation but I remember it's, you do the moles because you compare the moles to hydrogen was it? No it was carbon.	Combining calculating the amount of substance and defining relative atomic mass.
	7	I	OK, so what did I have to do with the ten grams to get an expression in terms of number of moles?	
	8	N	I can't remember the equation. I can sort of see it in my mind but I can't remember.	
	9	I	OK, thank you.	
			END	

June 2015 - Fourth attempt at amount of substance scenario

CR	CCL	ICL
2	5	3

Language guidance	Comment	I = Interviewer N = Neil	Transcript	Comments
	1	I	I've got ten grams of lead and ten grams of sodium. The lead has got fewer atoms in it. Can you explain why?	
	2	N	(p4) It's because the individual atoms are lighter or heavier so the individual atoms of iron are heavier than the sodium.	

3	I	Why are they are heavier? What is it about those atoms that makes them heavier?	
4	N	It's the amount of (p5) electrons, neutrons and (p2) positrons?	Seems unaware that electrons do not significantly contribute to the mass.
5	I	Right, that's a good one isn't it? (laughter)	
6	N	Positrons is something completely different. That's interesting I wonder why that sprung into my mind?	
7	I	(p5) Protons.	
8	N	Protons, that's weird. Protons makes complete sense.	Unable to recall the term protons.
9	I	Yeah, so positron is most probably a term you have come across maybe in a radiological sense?	
10	N	Yeah, will be. So that's the one I've been thinking about this year because we have been doing cancer, yeah. But the lead atoms have more of each of those. I was going to say molec, higher molecular weight overall? I think it's molecular weight because we calculated the weight didn't we? We had to calculate the weight. Don't ask me how to do that (laughter).	Positron met in a medical context. Refers to molecular weight rather than atomic mass.
11	I	Well, have we got molecules or atoms? This lump of lead then, have I got molecules or atoms?	
12	N	I suppo, I suppose they're molecules aren't they? (p6) I suppose they would be, would they be molecules at that point because they are actually a solid?	Considers them to be molecules because they are a solid.

13	I	Yeah? That's interesting. I can see a logic behind that but they would actually be referred to as atoms.	
14	N	Yeah. If you are measuring them, to me, that's why I said atoms because you would measure a particular atom but from what I remember of the calculations, if you were doing a molecule you would work out each of the atoms in that molecule individually.	
15	I	Yeah, so which atoms have we got exactly in that lump of lead.	
16	N	You've just got lead and in sodium you've just got sodium so in that case you would definitely have atoms. Yeah, I can vaguely see the calculation in my mind and when we do molecules it is each atom and then the total weight. We do something else to it which I don't remember. (laughter).	Deduces that they must be atoms.
17	I	So how would I say, express how many atoms I've got in those ten grams?	
18	N	Well, this came down to the calculation didn't it and that is how you worked it out. I cannot for the life of me remember the exact calculation though. I remember you worked out how much was in each, each of them weighed, I think and then you divided that into...	Unable to recall mole calculation.
19	I	OK, and then how would I express in a meaningful way to give the amount of substance or in this case the number of atoms. There's a particular type of unit we used to describe that?	
20	N	Was it moles?	Recalls correct unit.
21	I	Any idea what a mole is? (laughter)	

22	N	It's based around a hydrogen atom...	
23	I	Originally it was but then it changed to something else.	
24	N	(p3) It's based around a set weight of one of the elements. I thought it was a hydrogen atom. I remember it being based around a set weight.	Refers again to weight.
25	I	So what would you say there? Let's say it was hydrogen what would you say?	
26	N	I think hydrogen would be one so everything else would be based on that so, a random number but, iron could be ten per mole.	Struggling to provide an explanation of relative atomic mass.
27	I	Alright, thanks.	
		END	

Appendix 11

Interviews with Adam

Scenario 1- States of matter.

November 2012 - First attempt at states of matter scenario

CR	CCL	ICL
1	3	1

Language guidance	Comment number	I = Interviewer A = Adam	Comment	Comments
	1	I	I have a hot drink, I breathe on the hot drink and my glasses steam up, OK? Can you explain, as scientifically as you can what has happened there?	
Er - hesitation	2	A	Er (p36).	
	3	I	So let's take the first stage, I breathe on to the cup, what is going to happen?	
Yeah – informal word for yes	4	A	Yeah, but, I'm thinking I-even-can't explain it in Chinese. (laughter)	
	5	I	Well, that's interesting.	
	6	A	Yeah, (p2) it's a really like the very simple questions in life.	
	7	I	That's right it's a sort of everyday observation. Well, let's maybe start at the end. If my glasses have steamed up, what has formed on the glasses?	
	8	A	Gas.	Incorrect term – liquid has formed

	9	I	Gas, yeah?	
	10	A	The water become gas.	
	11	I	So water becomes gas. Is that what is on my glasses when they steam up?	
	12	A	Ah, steam up.	
	13	I	Yeah, yeah, so it is sort of like a fog.	
	14	A	Ah it's er (p1) first it's er gas and er, when it's like like er steam up on the glasses when the gas er contact the glasses, the glasses is cold and make it er er become liquid.	Frequent hesitation and repetition within a sentence.
	15	I	Excellent, alright so why, what happened for the water to go from being a gas to a liquid?	
Errr – extended hesitation	16	A	Errr (p4)	
	17	I	It's some of the ideas we talked about this morning, really.	
	18	A	What happen?	
	19	I	Yeah, so what's happened to the particles to go from being a gas to a liquid?	
	20	A	The (p5) er, the, how er ki kitic?	Struggling to say the word
	21	I	Kinetic.	
	22	A	The kinetic energy is decreased.	

	23	I	Excellent, alright. The kinetic energy of the particles is decreased so what happens to the arrangement of the particles?	
	24	A	Errr, become more closer, er (p7).	
	25	I	OK, yeah, alright, excellent and in terms of the water molecules themselves, has anything happened to them?	
	26	A	Err (p5) they have move closer?	
	27	I	Yes, OK but is anything happening between the molecules?	
	28	A	Er, I don't know.	
			END	

May 2013 – Second attempt at states of matter scenario

CR	CCL	ICL
2	10	1

Language guidance	Comment number	I = Interviewer A = Adam	Comment	Comments
	1	I	After a cold night, condensation forms on the inside of a window pane. Can you explain why?	
Oh – an exclamation.	2	A	(p5) Er (p4) oh because it's a cold night and makes the window become cold and the the the er water as er gas form become become liquid form so this happens.	

3	I	OK, why? What's happening? Let's think on a more microscopic level in terms of molecules. What is happening for that to occur in terms of the molecules?	
4	A	Er (p6)	
5	I	So you said it goes from gas to liquid...	
6	A	Yep	
7	I	Why though? What has changed?	
8	A	The temperature has changed.	
9	I	Yeah, OK so it's colder on the glass but what has changed in terms of the molecules?	
10	A	Ah, become closer, they will become closer.	
11	I	Why have they become closer?	
12	A	Er (p10) umm (p8) because like if you er increase the temperature the molecule will er faster and there will be er like (p2) er far away from each other and if the temperature go down I think the molecule will move slower and come closer.	Uses increase but then uses less sophisticated "go down" rather than decrease.
13	I	OK, Is there any words we could use, you know, you say they move faster they move slower, is there a more technical way we could describe that in terms of what the particles have?	

14	A	(p8) what what energy?	
15	I	Yeah, energy, OK and what form of energy?	
16	A	Erm (p8) kine what's that? Er, how do you? Kin er...	Struggles again to pronounce the word.
17	I	Can you write it down?	
18	A	Because...	
19	I	(laughter) Do you know the Chinese word for it?	
20	A	Yeah, yeah.	
21	I	What's the Chinese word for it?	
22	A	Er, dong nan	
23	I	Right, try putting that in your dictionary, see what we get.	
24	A	(p15) kin er.	
25	I	Yeah, yeah, that's the right one, kinetic.	
26	A	Kinetic.	Not recalled – obtained from online translator dictionary
27	I	OK, that's interesting. So you knew the word in Chinese. So, moving on a bit, what kind of molecule is water? So here we've got H_2O...	

	28	A	Yep	
	29	I	What could I indicate on it?	
	30	A	What do you mean by indicate?	
	31	I	Well, (p2) in terms of the distribution of the electrons here, in these bonds, where do they spend most of their time?	
	32	A	Er, the the two H atoms of the have a force...	Correct use of "atoms"
	33	I	Yeah.	
	34	A	(p2) two two (p8 – looking up word on smartphone) hydrogen bonds.	Word obtained from online dictionary.
	35	I	OK, where's the hydrogen bond here?	
	36	A	Erm, cough, (p5) I have no...	
	37	I	It's not there at the moment. To have a hydrogen bond we would need another water molecule.	
Ah ha – an utterance indicating agreement / understanding.	38	A	Ah ha two two.	
	39	I	OK, cause the hydrogen bond is between the two like that...	

40	A	Not two hydrogen?	Misunderstands hydrogen bonding.
41	I	No...	
42	A	So hydrogen and er oxygen?	
43	I	Hydrogen and oxygen, yeah. It's a really misleading word. It's an interesting one, you know, causes lots of students confusion because you think hydrogen bonding it's between hydrogens but no it's not it involves OH and NH where you get, which will then mean you can get this hydrogen bonding between two different molecules. Again the word bonding is misleading, we talk about these as being bonds, covalent bonds, where as really...	
44	A	It's not a bond.	
45	I	It's not a bond. What would we call it?	
46	A	Erm, van der Waals' force.	Names wrong intermolecular force.
47	I	Yeah, force isn't it? So it's where the terminology is not clear really this is easier to think of as attractions between molecules as forces and attractions between atoms in molecules as bonds. So a hydrogen bond is just a special form of a permanent dipole that is a bit stronger. Van der Waal is a temporary dipole.	
48	A	What is temporary dipole?	Does not understand temporary dipole
49	I	Right OK, when I say dipole any idea what I mean then?	

	50	A	No.	
	51	I	So dipole, is a charge difference yeah? So di pole kind of suggests that kind of thing, like two poles so like in a magnet you've got positive and negative. It's that sort of idea so the oxygen is slightly negative and the hydrogen is slightly positive. OK, so we have a permanent dipole here as in that oxygen is permanently a bit negative and that one is permanently positive, why?	
Is easy – can easily	52	A	Because er (p3) hydrogen is easy to lose the electron?	
	53	I	Not really, no. You've got to think about this covalent bond and where these two electrons are spending most of their time.	
	54	A	Er, yes this er, near the oxygen.	
	55	I	Yeah so they spend more time down here. Why?	
	56	A	Because er (p8) the oxygen have stronger force er...	
	57	I	Any idea what the term was we used for this?	
	58	A	(p5) cough we have learnt bit of this er, in China but not too much.	Not familiar with electronegativity.
	59	I	No?	
	60	A	No.	
	61	I	So, electronegativity? Ring any bells? (p2) So it's a term we have used at various points this year, yeah? So of course, you can get something from the word there so obviously electro to do with electrons and negativity so really	

		it's the ability of an atom to attract a pair of electrons in a covalent bond. So the oxygen has a higher electronegativity than hydrogen so it attracts those electrons more strongly. So it results in the oxygen being a bit negative and the hydrogen being a bit positive, OK? So what sort of molecule do we call this? (p13)(laughter) polar? So this is a polar molecule because it has got this polarity to it OK?	
62	A	Yes.	
		END	

March 2014 – Third attempt at states of matter scenario

CR	CCL	ICL
2	4	1

Language guidance	Comment number	I = Interviewer A = Adam	Comment	Comments
	1	I	I have a cup with a hot drink, I breathe on the cup and my glasses steam up. Can you explain why?	
	2	A	Errr, because the the the er the hot drink is hot and the your glasses is colder than the hot drink's temperature and if you er what's that (blows)	
	3	I	Breathe	
	4	A	Breathe and the er air will (p2) er (p1) makes the hot air come to your glasses and the two different temperatures makes the steam.	

	5	I	Ok so when you say the erm drink is hot what do you mean it's hot?
	6	A	(p3) er (p2) high temperature.
	7	I	So what do you mean by a high temperature?
	8	A	More than the room temperature.
	9	I	OK but I mean OK, let's get down to you know molecules.
More faster - faster	10	A	Ah ha, the molecules move more faster.
	11	I	So why do they move faster?
	12	A	Because the temperature is high and the er (p2) that makes them move faster and the space between the two molecules is larger.
	13	I	OK, because what do they have more of?
	14	A	More of?
	15	I	If they are moving faster what must they have more of?
	16	A	What do you mean by more?
	17	I	What makes them move faster (p6). OK, well let's look at the molecules, what actually are they in the drink?
	18	A	Er, water.

19	I	Water, so what changes in terms of the water molecules say when they go from being a vapour to condensing from the glasses. What changes about them?
20	A	(p3) Er the water molecules come close and er from the er gas to the liquid.
21	I	OK, anything else about like, what's going on between the molecules?
22	A	Hmm, no.
23	I	No, OK.
		END

Appendix 12

Interviews with Adam

Scenario 2 - Amount of substance.

November 2012 - First attempt at amount of substance scenario

CR	CCL	ICL
2	1	0

Language guidance	Comment number	I = Interviewer A = Adam	Comment	Comments
	1	I	So I have ten grams of lead and it has fewer atoms in it than ten grams of sodium. Can you explain why?	
Er - hesitation	2	A	Can I see the question?	
	3	I	Yep, so ten grams of lead has fewer atoms in it than ten grams of sodium.	
	4	A	What is it?	
	5	I	So lead is a heavy metal, yeah? You get it on roofs, sometimes pipes are made from it. Yeah? So it's like gold is a heavy metal...	
Yeah – informal word for yes	6	A	Ah, yeah...	
	7	I	OK, so it could be gold, it wouldn't matter. It could be ten grams of gold has fewer atoms in it than ten grams of sodium.	

8	A	(p20) Because the (p2) the lat, atom is bigger (p2) and (p5) and this two things er, or it was, sol, solid...	Refers to the atom being bigger.
9	I	Yep, both solid.	
10	A	Both solid, er, (p2) and the lead atom is bigger, bigger than sodium in ten grams just to have er, this er, enough space for lead can't can't have the same atom as sodium.	
11	I	OK, so when you say it is bigger, what do you mean?	
12	A	It's er, the, the atom is bigger.	
13	I	But what does that mean, it's bigger?	
14	A	(p3) Er, (p8) because it's (p3) er, is er, how do say that table?	Unable to name the Periodic Table.
15	I	Periodic table.	
16	A	Periodic table the er, why, because it have more er, at (p7). How do you say this word?	Unable to say electron.
17	I	Electron.	
18	A	Electron. Because it have more electron than sodium. So then it is bigger than sodium.	States that the atom is bigger because it has more electrons.
19	I	It is bigger than sodium.	
20	A	Yeah.	

	21	I	OK, thank you. END	

May 2013 - Second attempt at amount of substance scenario

CR	CCL	ICL
2	3	1

Language guidance	Comment number	I = Interviewer A = Adam	Comment	Comments
	1	I	Ten grams of gold has fewer atoms in it than ten grams of lithium.	
	2	A	Because the, the gold atom is bigger than lithium.	
	3	I	OK, so let's try and make that more scientific. You said they are bigger but what do you mean?	
It have – it has	4	A	Er (p4) It have more electrons around it.	
	5	I	OK, (p6) is that all?	
	6	A	Er, (p15) yeah, that's all.	Appears to consider bigger to refer to the atomic radius rather than any significance of mass and the nucleus.
	7	I	I mean, what's significant in terms of the size of an atom? Is it the electrons that are significant?	

Ah – an exclamation	8	A	(p 27) Ah, er, er, the er, (p5) er, the gol, gold the molecule mass is bigger.	After prompting, recognises a significance of mass.
	9	I	Yeah, OK, so are we talking about molecules here?	
	10	A	Ah, no atom.	After prompting, recognises that atom is the appropriate word.
	11	I	Good, what's the difference between a molecule and an atom?	
One atoms is one things – one type of atom.	12	A	Er, atoms just have one one, one er, one atoms is one things but the molecules is er, er, like er, made by the atoms.	Struggles to find the vocabulary to define a molecule.
	13	I	(p4) Yeah, basically...	
Most smaller - smallest	14	A	In Chinese when we learn the atoms the definition is like in chemistry the most smaller (p2) unit?	
	15	I	Unit, yeah, good. If I have a lump of gold, why is that not a load of gold molecules?	
	16	A	Because gold is er, (p8) it's er, single substance.	
	17	I	OK, yeah, you're on the right lines. So when I say a chlorine molecule, how does that distinguish it from chlorine atoms?	
	18	A	Ah, what do you mean by distin, distinguish?	Does not know the meaning of "distinguish".
	19	I	So, I can have a chlorine molecule and a chlorine atom but what is the difference?	

	20	A	The (p7), the erm, chlorine atom is er, is like er, is er, is not an actual.	
	21	I	OK, so it won't exist on its own but what is different about the chlorine molecule to the atoms?	
They different – they have different	22	A	(p12) they different properties.	
	23	I	Well it will do but what has happened to form the molecule. For them to join together. What sticks the two atoms together.	
	24	A	Er, the bond.	
	25	I	The bond, that's the difference, yeah? They've got covalent bonds. Molecules are two or more atoms chemically joined together.	
			END	

March 2014 - Third attempt at amount of substance scenario

CR	CCL	ICL
2	4	0

Language guidance	Comment number	I = Interviewer A = Adam	Comment	Comments
	1	I	I have ten grams of lead, OK? and it has fewer atoms in it than ten grams of sodium. Can you explain why?	
Er - hesitation	2	A	What's lead?	Does not know what lead is.

Erm – hesitation	3	I	Lead? Erm, a metal element, symbol P B, lead. It's quite a heavy metal used on roofs but it doesn't really matter what the element is OK. It could be anything but I have ten grams of this substance, let's say lead, and I have ten grams of sodium OK? But the ten grams of lead has fewer atoms in it than the the ten grams of sodium.	
	4	A	Because the, the lead atom is bigger than the er, sodium atom.	Refers to the atom being bigger.
	5	I	What do you mean bigger?	
	6	A	Er, the (p3) the atom is bigger.	
	7	I	But what does that mean, bigger?	
	8	A	Because, er, I think they are in the same group the sodium and lead. Is it?	Thinks they are in the same group.
	9	I	Well, they are not actually...	
	10	A	OK, but er, if they were in the same group it is easier to explain.	
	11	I	Well, let's assume that they are, that doesn't really matter. Let's say they are sodium and erm, caesium. So caesium is further down the group, it really doesn't matter what the element is it is just that one element has got fewer atoms in ten grams than the other.	
	12	A	Because er, (p2) er, they are in the same group, the atoms size becomes bigger as it goes down.	
	13	I	OK, but what does that mean it gets bigger?	

14	A	The erm, relative mass is bigger?	Qualifies bigger as a greater relative mass (omits atomic)
15	I	OK, so what does the atom have more of?	
16	A	More of?	
17	I	So its relative atomic mass is greater. Why? (p5) What makes up an atom?	
18	A	Er, the electrons and er, (p3) what's that called?	
19	I	I can't say (laughs).	
20	A	Electrons and er, neutrons.	
21	I	OK, so they are subatomic particles and make up the atom but what makes an atom bigger?	
22	A	Bigger, er, get more electrons.	Considers more electrons as the reason why an atom is bigger.
23	I	More electrons, OK.	
		END	

Appendix 13

Interviews with Kirsty

Scenario 1 - States of Matter.

November 2011 - First attempt at states of matter scenario

CR	CCL	ICL
2	4	0

Language guidance	Comment	I = Interviewer K = Kirsty	Transcript	Comments
	1	I	The kettle boils and steam forms on the window pane. Can you explain what's going on there?	
	2	K	(p2) It's so hard to explain something so simple.	
Yeah – an informal word for yes	3	I	Yeah, that's right…	
	4	K	Something you've seen every day, to actually put that into a chemistry explanation. (p1) It's evaporating.	Struggling to find words to explain.
OK – a word denoting approval	5	I	OK	
	6	K	Yeah, that's right isn't it?	
	7	I	So when is it evaporating?	

	8	K	Erm, when it reaches boiling point and the steam comes off but then once it hits the window it cools and then it forms back into water.	
	9	I	Right, OK, excellent. So let's go back, so why is it evaporating?	
	10	K	(p1) I don't know how to explain it.	
	11	I	What is happening in terms of the particles in the kettle when it starts boiling?	
	12	K	(p2) Once they become steam they start to move about, spread out because they are no longer a liquid so they just start to move out and then obviously it's going to hit a window and that's when it cools and that's when it becomes water.	Does not qualify – move about *more*.
	13	I	So why do they start moving about more?	
	14	K	Because they can, they'll fill a space it becomes like…	Does not formulate an explanation using kinetic energy.
	15	I	But if I had my kettle with some water in and it's not turned on. The water sits in the kettle there, I turn it on and then steam will start coming out.	
	16	K	(p3) because it's boiled and steam's produced. .	
	17	I	But what does that mean in terms of the particles? Why have they boiled?	
Som'in - something	18	K	Because they must get to a certain temperature and then they need to move off or som'in like that.	

	19	I	OK, what do you mean by getting to a certain temperature? (p2)	
	20	K	A temperature that they need to be at in order to for that action to take place.	Vague statement
	21	I	But what does temperature mean in terms of the particles. Let's get down to these water particles.	
	22	K	I think that's about as much as I am going to be able to answer.	Unable to describe a particulate model of molecular motion.
	23	I	OK, excellent, thank you.	

April 2012 - Second attempt at states of matter scenario

CR	CCL	ICL
3	13	2

Language guidance	Comment	I = Interviewer K = Kirsty	Transcript	Comments
	1	I	I'll just ask you a couple of these scenarios.	
	2	K	Oh no, I won't know any of these.	
	3	I	After a cold night, condensation forms on the inside of a window pane, can you explain why?	

	4	K	It's because (p1) so the heat inside the room creates like if there's water in there vapour and then it's a gas and it's got lots of energy and then when it hits the, the coldness outside makes the window cold so the heat, when the gas, water vapour, hits the-cold-window it then drops down to a liquid basically. Energy gets taken away and it gets dropped down to a liquid.	Unusual phrase – "dropped down"
	5	I	So what changes in terms of the molecules?	
	6	K	They go from free, free flowing with lots of energy down to, they become slightly closer together. They are touching and they can move freely but they are always touching.	
	7	I	OK, any particular kind of energy?	
	8	K	Kinetic	
	9	I	OK and what about in terms of them being actual water molecules so when we think about what's changing in terms of the interactions between those water molecules specifically.	
Uh – used to express hesitation or uncertainty	10	K	It is the (p1) I don't know, I am going to say I don't know if it is to do with hydrogen bonding or the Van der Waal bonding but uh (p1) I feel like I knew all this last term but now it's gone.	Highlights the confusing language of hydrogen bonding and Van der Waal forces
	11	I	So that's an interesting comment isn't it?	
	12	K	It's gone, unless you are rereading it and stuff like that. I don't know, unless it would be the attraction.	If the language is not regularly used then fades.

	13	I	So what attraction would there be between the water molecules?	
	14	K	Actually it's the hydrogen bonding between them in the molecules so the attraction between oxygen and the hydrogen of separate ~~because~~ the oxygen is more electronegative and it will slightly attract hydrogens ( ) from a different molecule, erm, and then as it goes to liquid I don't know, less energy. I am not sure.	Electronegative not used correctly. Omission - atoms
	15	I	Let's go back to that, so oxygen is more electronegative you say.	
Ahmm – a sound relating to an affirmation.	16	K	Ahmm than hydrogen.	Completes the statement as a comparator with hydrogen.
	17	I	Than hydrogen so what is the consequence of that?	
Yeah – an informal word for yes	18	K	It's a dipole, yeah?	
	19	I	Yeah, and what does that mean?	
Erm – a hesitation.	20	K	Erm, it means that there's, there is polar ends so well negative positive so electrons would be, there's more electrons no there's two lone pairs on the oxygen and (p1) that's more negative so it will be, something positive with less electrons will be attracted to it.	Keeps on modifying the sentence. Strong example of interlanguage – searching for the correct language / explanation. She does not provide an explanation of polarity relating to a difference in

				electronegativity.
	21	I	So what is attracted to it?	
	22	K	The hydrogen.	
	23	I	From where?	
	24	K	A different water molecule. So that's how they are linked together doing that.	
	25	I	So are there any hydrogen bonds with this water vapour that is in the room.	
Ah – an exclamation of surprise.	26	K	(p2) Ah no, I don't think that has dawned on me before.	
	27	I	OK, excellent	
			END	

June 2013 - Third attempt at states of matter scenario

CR	CCL	ICL
2	9	1

Language guidance	Comment	I = Interviewer K = Kirsty	Transcript	Comments
	1	I	I have a hot drink, I breathe on the hot drink and my glasses steam up. Can you explain why?	

Them- those	2	K	Erm, I can't remember. I wouldn't know how to put it in to words. I know what, you know that it's. Right you've got a hot drink, you breathe on it. Cools down the molecules inside the hot drink causing the evaporation to a gas and then it hits your glasses which are cold causing them to recondense. Something along them lines with more chemistry.	Describes breathing on it as cooling down the molecules and causing evaporation. Extension of condense – incorrect as the molecules have not previously condensed.
	3	I	OK, so why do the molecules recondense? What happens to the molecules when they recondense?	
	4	K	Because we are increasing the entropy aren't we if it is going from a liquid to a gas? We are increasing disorder to a gas if it's going from liquid to steam gas, gas molecules and then when they were hitting the cold we are taking energy away? Decreasing it yeah.	Incorporates a new concept.
	5	I	Taking energy away and what happens to the molecules in terms of like the way they are arranged?	
	6	K	So they go back to a more structured water molecule.	
	7	I	Were they water molecules as a gas then?	
	8	K	No they were all separated so then the bonds reform.	Confusing a body of water and individual water molecules.
	9	I	So how are they arranged in a gas compared to liquid?	
	10	K	More spaced out in a gas compared to a liquid aren't they? If they are more spaced out they are less likely to bang in to each other aren't they?	

August 2014 - Fourth attempt at states of matter scenario

CR	CCL	ICL
3	14	1

Language guidance	Comment	I = Interviewer K = Kirsty	Transcript	Comments
	1	K	I did explain polar bonds to him as well. We were talking about H_2O and I was telling him about...	Use of the chemical formula
	2	I	That's brilliant, because that is one I wanted to ask you about actually	
Yer - you	3	K	Did yer, what H_2O.	
	4	I	H_2O, about water.	
	5	K	I actually quoted you I think and said water is the most important molecule on the planet ever and told him about the electrons never staying still although it being a neutral charge the electrons constantly moving which was causing negative and positive charges at points on the molecule.	Incorrect description suggesting the water molecule has a neutral charge. Possibly confusing with a temporary dipole.
	6	I	Why do you get that charge difference?	
	7	K	Due to the (p1), it's to do with the pull, the positive, the pull between the atoms isn't it?	
	8	I	Ahmm.	
	9	K	I can't think of the words.	Struggling to explain.

10	I	So why does one pull, because that's why you end with one different to the other isn't it...
11	K	Yeah. Because it has a higher erm, more protons in the middle oxygen doesn't it?
13	I	Yeah, ahmm.
14	K	(laughter) feel like I'm being tested.
15	I	Sorry I suppose it is a bit like that isn't it?
16	K	Yeah.
17	I	I'm just kind of really interested in the, it's just that you started really interestingly in terms of saying how you kind of started explaining things to your brother.
18	K	Yeah, he loves it (laughter).
19	I	That's so useful to make use of isn't for the coming years? Talking about stuff you're doing and explaining it.
20	K	Yeah, it is. Yeah because nobody's been interested up until now. That's where I learn by talking about it but the problem is he doesn't know if I am right or wrong.
		Break – after a discussion about Kirsty's learning experience the discussion returned to the scenario later in the interview.

	21	I	Why is there a difference in the polarity?	
	22	K	(Laughing) You see in my head I am now seeing a hydrogen with two oxygen atoms stuck to each other, erm.	Describes incorrect atoms on the molecule.
	23	I	Hydrogen with two oxygen atoms stuck to it?	
Gonna – going to.	24	K	Sorry, the other way round (laughs) erm, and it, like the hydrogen are tiny in my head and the oxygen's bigger so and then it. I wish I could draw it, if I could draw it, it would be easier. I would draw it how you've taught me. So (p1) and then inside in my head I am thinking that they've got all these protons. Oxygen's 16 so it must be 8 and then the hydrogen's the 1 isn't it? So I'm thinking well there's these more positive in the middle so it's gonna have more of a pull towards the oxygen.	Recognises error and corrects.
	25	I	OK, is there a particular term for describing about the oxygen…	
Wanna – want to.	26	K	I can't remember. I wanna say electronegativity.	Recalls correct term but is uncertain.
	27	I	Well I would.	
Oh – an exclamation	28	K	Oh (laughter). Is it electronegativity then?	
	29	I	Yeah.	
	30	K	So the electronegativity for oxygen is stronger than the hydrogen electronegativity due to the amount of protons in the middle. Is that right?	Uses electronegativity correctly but higher would have been more appropriate than "stronger".

31	I	Yeah, basically we could go with that alright. But why is the molecule shaped like that?	
32	K	Because of the two (p1) is it, what are they again? The electrons. So they have a downward force pushing on the bond.	
33	I	Is there a particular thing we call this when we've got two electrons…	
34	K	Ah, erm, yeah, there is (p2). I can't remember.	
35	I	Lone pairs	
36	K	Lone pairs of electrons. I knew that.	Immediate repeat of term
37	I	So what about attraction between water molecules?	
38	K	Well it is because of, the attraction between the water molecules do you mean?	
39	I	Yeah.	
40	K	So well obviously it's the polar, between the polar bonds the negative…	
41	I	So which bit's negative and which bit's positive.	
42	K	Oh I can't remember. END	Unable to explain the structure of the water molecule further.

June 2015 - Fifth attempt at states of matter scenario

CR	CCL	ICL
3	14	4

Language guidance	Comment	I = Interviewer K = Kirsty	Transcript	Comments
	1	I	Kettle boils and the steam hits the window pane and it forms water can you explain why?	
	2	K	(laugh) So the kettle boiling it's producing a steam which is fast moving molecules. I'm just going to say it, if it's wrong it's wrong...	
	3	I	There's no wrong answer.	
	4	K	Different isn't wrong (laughter) erm which is in gas form so they are moving really quickly erm, and they're hot. When they hit the window it cools them down which slows their movement which therefore, turns them from the gas form to liquid form because it slows down how fast they move.	Unusual use of the word "form" – "state" more appropriate?
	5	I	So why do they turn from a liquid to a gas?	
	6	K	Because they, from a liquid to a gas?	
	7	I	In the kettle...	
	8	K	Because they are heating them up.	

9	I	You are heating them up so what's changing in terms of the molecules?	
	K	Their bonds?	
10	I	Elaborate.	
11	K	Erm, hold on a minute, so the bonds holding the molecules together so in a liquid form (p1) see in my head I have the molecules like as layers over each other transient moving erm and as we heat them up we're starting to vibrate them and change their bonds in contact with each other (p1) becoming looser?	Referring to bonds between the molecules. Refers to starting to vibrate them rather than increasing vibration. Interesting use of looser. Nonstandard use of transient
12	I	Are we breaking the bonds between them?	
13	K	The molecules?	
14	I	Between the molecules.	
15	K	Yeah.	
16	I	OK, and what would those bonds be between water molecules?	
17	K	Covalent bonds (fading)	Incorrect term but appears to be unsure.

18	I	Between the water molecules?	
19	K	**No**, between the water molecules? Ah, gosh, they-are Van der Waals? No. Is that right or not?	Corrects after prompting but is still unable to recall hydrogen bonding.
20	I	No, no.	
21	K	But I do remember some bonds.	
22	I	I am surprised because if anything they are something I might have thought, inadvertently throughout your course you would have been referring to these.	
23	K	They're electronegativity aren't they, ah no that's the. Electronegativity that's the electrons pull towards each other the nucleus aren't they? Time – 1h	Corrects understanding of electronegativity
24	I	Go on, so what's electronegativity?	
25	K	Isn't it the positive pull of the negative electrons?	Confusing statement
26	I	In what situation?	
27	K	Of a molecule so like an oxygen molecule the amount of electronegativity within the molecule (laugh). So you've got your positive, your nucleus in the middle with your protons (p1) and your neutrons and it's, is the amount of electronegativity holding the electrons within the rings on the molecule. I'm not explaining this very well. If I became a Chemistry teacher I would have to do some proper work wouldn't I? (laughter). It's really hard to remember it. I think I've never touched on anything you taught me again (laughter)	Confusing statement about electronegativity

28	I	But you must have, in your course, considered the interactions with water molecules you know like solutions and things...	
29	K	Yeah, but I never had to remember what they were called. I knew it, it was innate. It was just there, I never had to (p1) having to explain it or write it in an assignment I would have to know all the names but I guess you change the way you think. It was always at the back of my head. I often say let me think logically about this and then the bits that I learnt four years ago are just an innate. I wouldn't know how to pull them forwards to talk about them. I can see the bonds between them, I can see that I have the drawing them on a piece of paper I just can't remember what on earth they are called.	Kirsty feels that her understanding is somehow automatic but cannot recall specific terms that she has not had to use for years.
30	I	So if I said hydrogen bonds?	
31	K	Yeah, yeah, yes (laughter). They're all there it's just difficult to remember.	Recognition of term once stated.
32	I	So the steam goes up and hits the window pane so what happens then?	
33	K	The molecules slow down.	
34	I	So what do they lose when they slow down?	
35	K	They are losing energy, losing heat.	
36	I	What sort of energy? (p1) what is heat?	
37	K	What is heat did you say?	
38	I	Yes.	

39	K	Thermic energy.	Thermic – adjectival form of thermal
40	I	Yeah but what we actually measuring what is heat energy? Thermic energy is just another word for heat energy really.	
41	K	Ah huh. (p2) I don’t think I...	
42	I	If something is hotter than something else what is happening? If I cooled something down to absolute zero as cold as anything could be what’s happening?	
43	K	I don’t know, you’ve stopped it moving?	
44	I	Yeah, stopped what moving?	
45	K	Stopped the molecules moving.	
46	I	So what is heat energy?	
47	K	Kinetic energy, the amount that it is moving? Is that what you’re getting at? Sorry, I nearly said kinetic the whole three words ago (laughter). I don’t think I understand what you are looking for sometimes, sorry.	
48	I	No, no, OK.	
49	K	So they hit the window and they lose kinetic energy, yeah?	
50	I	Ah hum.	

51	K	Because they’re not moving as much, therefore, they can reform.
		END

Appendix 14

Interviews with Kirsty

Scenario 2 - Amount of Substance.

November 2011 - First discussion of amount of substance.

CR	CCL	ICL
4	6	0

Language guidance	Comment	I = Interviewer K = Kirsty	Transcript	Comments
	1	I	We've got moles calculations, so what is the equation for that?	
	2	K	Grams over rams, that's how I've remembered it.	Uses a short rhyme to remember the relationship.
	3	I	Grams over rams?	
	4	K	Yeah, John told me that last week.	
Yeah – informal word for yes.	5	I	Oh yeah, that's quite a nice one.	
	6	K	Sometimes the A R was confusing, because like, what does it stand for? Quite often we're visual and you think about the rams and you can see it.	Mentions how the symbolic language can be confusing.
	7	I	So, as soon as you know that equation you can work out any sort of mole calculation that relates mass to number of moles. So for example, twenty	

			grams of phosphorus, we’ve got a mass and we want to know the number of moles so what do I need to divide the twenty by?	
	8	K	The relative atomic mass, thirty one.	Third way of stating RAM
	9	I	Thirty one.	

April 2012 - Second discussion of amount of substance scenario

CR	CCL	ICL
3	6	4

Language guidance	Comment	I = Interviewer K = Kirsty	Transcript	Comments
	1	I	Ten grams of gold has fewer atoms in it than ten grams of lithium. Can you explain why?	
	2	K	Because the relative molecular mass is different so ten grams of gold has less molecules so the molecules of gold are, the relative molecular mass is bigger than the lithium so, yeah.	Recognises that RAM is the relevant concept but refers to molecular mass and molecules.
	3	I	OK, erm so how would I describe, in terms of the number of atoms, how would I describe? If I was going to say ten grams of gold and I’ve got this many atoms, what might I use?	
	4	K	Moles.	
	5	I	Right, so what is a mole?	

Ahhh – an exclamation.	6	K	A mole is ahhh, (p2) is the amount, see I don't like this because they changed it because then they made it carbon right or whatever they did but it's the amount of, the the weight of a particular, like it's one whole thing which is the same as let me see, is it six grams of carbon twelve? The same, that has the same amount of moles in it as six grams of carbon twelve. Is that right?	Produces a very confused explanation of a mole. Refers to weight. Refers to six grams of carbon twelve.
	7	I	Why would it be six grams of carbon twelve?	
	8	K	(p3) I don't know, I think it is something to do with hydrogen because a mole is, I wanna say six point two three times ten to the power of something but...	Refers to Avogadro's constant as 6.23
	9	I	Well, you are along the right lines.	
	10	K	I think hydrogen was that and then carbon, they can transport it better, so then it's that so I don't know, it's something like that. A mole is, yeah, it's six point two three times ten to the power of, is it four? No, no? They're in there but they are not right.	
	11	I	The correct answer is six point zero two times ten to the twenty three.	
	12	K	Ah, that was the twenty three. Yeah, and it's the same number moles you find in six grams of carbon that you, six grams of carbon makes one, is one mole. The number of molecules in six grams of carbon is one mole and then you are going to have the same amount of molecules to make up one mole of something else.	Still referring to six grams of carbon – confusing atomic number and mass? Still referring to molecules.
	13	I	If it's carbon twelve...	

14	K	Is it carbon twelve? But they changed it, they should have kept it to hydrogen shouldn't they?	
15	I	But that doesn't matter does it? If it was hydrogen then, how would I know that I had one mole of hydrogen?	
16	K	One mole of hydrogen is in (p1) oh I don't know, six that's six point o two times ten to the power as in one gram of hydrogen, isn't that right?	
17	I	That would be one gram wouldn't it?	
18	K	One gram of hydrogen is one mole, is in one mole, that's it. The same number of molecules so it's one, yeah one mole of hydrogen is in one gram of hydrogen. Is that right?	Recognises that one gram of hydrogen would contain one mole.
19	I	So what would it be for carbon twelve?	
20	K	Carbon twelve it's, isn't it six grams? Six grams, no?	
21	I	If it's carbon twelve...	
22	K	Twelve grams. Is that it? Yeah. Then it's the six that is getting in there, six point o two three, yeah.	Realises that it must be twelve grams.
23	I	That is a really interesting answer, thank you.	
		END	

June 2013 - Third attempt amount of substance scenario.

CR	CCL	ICL
3	8	1

Language guidance	Comment	I = Interviewer K = Kirsty	Transcript	Comments
	1	I	Ten grams of lead has fewer atoms in it than ten grams of sodium. Can you explain why?	
	2	K	My instant reaction without looking anything up is that lead must have a smaller atomic number than sodium. Therefore the relative atomic mass for lead is less.	Incorrectly refers to atomic number and then switches to relative atomic mass. Incorrectly states that the relative atomic mass of lead is less.
Ahmm – an acknowledgement of the response	3	I	Ahmm.	
	4	K	I also want to talk about Avogadro's constant and carbon 12.	
	5	I	Why? What is the significance of those?	
	6	K	I'm afraid I can't remember exactly but I seem to think that I would have to do something like dividing grams by relative atomic mass. Oh, I know if I could jog my memory that would be so much better!	Recalls correct calculation.

	7	I	So if ten grams of lead has fewer atoms in it than ten grams of sodium, what does that tell us about the lead?	
	8	K	That it's relative atomic mass must be greater.	Arrives at the correct conclusion.
	9	I	OK, great, thanks.	

June 2015 - Fourth attempt at amount of substance scenario.

CR	CCL	ICL
3	10	2

Language guidance	Comment	I = Interviewer K = Kirsty	Transcript	Comments
	1	I	I have ten grams of lead and I have ten grams of sodium and in the lead there are fewer atoms than in the sodium. Why would that be the case?	
	2	K	I don't think, cos I don't understand...	
	3	I	OK, so I have ten grams of lead and I have ten grams of sodium, so the same mass...	
	4	K	But different at, different molecules...	Refers to molecules as in previous interviews (default term for particles?).
	5	I	Different number of atoms.	

6	K	The only thing I would say is just they are different molecules.	
7	I	What way is the lead different molecules to the sodium?	
8	K	Cos it's formed by different, like er, a different number of protons and neutrons.	Refers to subatomic particles.
9	I	So what would be different about the, is molecules the right word for the lead compared to the sodium?	
10	K	What's the sign for lead?	
11	I	P B	
12	K	P B, trust you to chose one that I don't know.	
13	I	Yeah, but you see it doesn't matter, it could be any element from the Periodic Table.	
14	K	OK.	
15	I	So I have ten grams of that substance, could be gold, it could be anything, what is different? Have I got molecules there? Let's deal with that first. If I've got ten grams of lead, gold what have I got?	
16	K	Elements.	
17	I	Elements. OK, what's a molecule?	
18	K	You've already said atoms so you're not getting at different atoms...	

	19	I	Well what’s the difference between atoms and molecules?	
	20	K	I don’t think I know.	Unable to describe the difference between atoms and molecules.
Right – an acknowledgement.	21	I	Right, OK.	
	22	K	If I could try and recall, I’m just going to have to tell you what is in my head.	
	23	I	Yeah, yeah. That’s what I want to know.	
	24	K	If I am trying to recall my revision notes and what you taught me. I have the idea of an atom as a single thing and molecule being more than a single thing. So, a molecule of something being five of that.	Simple terminology.
	25	I	OK, cool. So if I have a lump of lead do I have atoms or molecules of lead? Obviously, I’ve got billions and billions of them...	
	26	K	Yeah.	
	27	I	But would I have atoms or molecules?	
	28	K	You would have billions of atoms forming the lead.	
	29	I	Right, OK. So would they be forming molecules of lead?	
	30	K	(laughs) I don’t know. I think so.	

31	I	OK, brilliant...	
32	K	I used molecules because you said atoms and I thought well I can’t say atoms then.	
33	I	What is different about the lead atoms compared to the sodium such that it means I have got fewer atoms of lead?	
34	K	The number of protons, now then neutrons are neutral and protons are positive, electrons are negative. What is it that gives it it’s mass? Is it the neutrons that give the atoms the mass? You must have more neutrons in the lead than in the sodium. If that’s what gives it the mass.	Recalls some aspects of atomic structure.
35	I	OK, so how could I say like how many atoms I have in that lump of lead? What sort of language might I use to represent the amount of atoms there?	
36	K	I think you would just have to use the word atom.	
37	I	So I would say like I’ve got two hundred billion atoms...	
38	K	Yeah...	
39	I	So, there is no sort of language that is used to give a representation of the number of atoms?	
40	K	There must be (laughter) but not that I can remember. Tell what you would say though?	
41	I	Well, a mole.	

	42	K	Ahhh, well obviously a **mole** (laughter). Yeah.	Feels that the answer is obvious.
	43	I	OK, so why when I was talking about it would that not kind of...	
	44	K	Yeah, I just didn't think you were getting at mole.	
	45	I	Why? So what does a mole mean?	
Oh – an exclamation.	46	K	A mole is used as a, it's a universal measurement isn't it? Of (p1) Oh, (p2) now I am trying to recall that. I can't even remember what a mole is. I can, but there is a sentence that I knew off by heart. I think that is part of the problem, a lot of it is learning off by heart rather than learning. Which I also learnt through this degree, learnt how to learn. It's hard when you stop learning and knowing things off by heart isn't learning. So why do I want to say one point six three or something and I want to say Avogardo's constant as well. See they are all in there, I just have to pull them out and put them in the right order (laughter). So a mole is the equivalent to one point six three of (p1) is it F E? Iron was it?	Comments on rote learning Mispronounciation of Avogadro's States an incorrect value States iron as the standard
	47	I	Not iron, carbon.	
	48	K	**Carbon**. One point six three grams of carbon was used to, universal measurement.	
	49	I	So that's really fascinating. So the actual number is six point zero two times ten to the twenty three. Where did one point six three come from?	Continues to refer to the same value
	50	K	I've no idea but I remember it now that you have said it. Maybe it's because iron is a major part of the body. So every year I have talked about	

		and learned about iron.	
51	I	So might that be the most common way you might have come across that concept?	
52	K	Yep, and I haven’t touched on chemistry, fundamental chemistry. I have touched on chemistry in biological terms.	
53	I	Yeah, but you must have been using concentrations and working out amount of moles...	
54	K	Yeah.	
55	I	So you are using it quite a lot but the...	
56	K	Fundamental is mish mashed in my brain, like a tornado. There’s no way I could sit down and do one of your exams now I have to say. Yeah, I can remember it being six point zero two two now. I can see it on one of my posters in the kitchen.	Refers to how these fundamental things have faded with time.
		END	

Appendix 15

Interview students' CLDT results

Date	October (%)				December (%)				May (%)			
Section	Ferne	Linda	Evan	Mean class	Ferne	Linda	Evan	Mean class	Ferne	Linda	Evan	Mean class
affixes	90	55	60	58	100	90	50	74	100	95	70	72
fundamentals	50	100	83	64	100	100	100	89	100	100	100	84
Word family acids	20	20	0	27	80	70	60	35	35	55	55	43
Word family kinetic	50	20	0	30	100	50	80	32	30	25	45	34
symbolic	40	60	100	60	80	100	100	71	100	80	100	78
Non-technical	60	30	90	56	80	90	80	73	90	90	90	78
Word choice	30	20	20	19	40	50	10	39	60	30	40	46
Total score	54	43	34	44	83	64	64	55	59	63	73	59

Appendix 16 – Chemical Language Diagnostic Test

The Language of Chemistry – how well do you know it?

Every subject has its own specialist vocabulary and in order to engage with the subject community it is important to be able to understand and converse using this language.   This is just the same as going on holiday and learning a foreign language. If you really want to get along with the locals you need to be able to speak the lingo!

The aim of this quiz is to help you to see how well you know different aspects of scientific language and more specifically the words that you will be using in chemistry this year.   This is a paper version that will be modified to become a fully functioning online quiz in 2014.

Name ……………………………………………………………..

Section 1 – Scientific affixes

Many scientific words in English have their origins in Greek or Latin words. As a result, you will find that the first part (prefix) or last part (suffix) of words with similar meanings have kept the same Latin or Greek word. If you know some of these common affixes it is possible to work out the meaning of new and unfamiliar words.

For each of the meanings below choose the correct affix from the list at the bottom of the page. The first one has been done for you.

Meaning	Affix
water	Hydro-
outside	
hating	
inside	
maker	
same	
between	
single	
containing iron	
within	
many	
double	
loving	
break down	
small	
containing nitrogen	
salt	
one thousandth	
large	
all	

Ferr-	Hydro-	Iso-	-phile	Mono-
-gen	-lysis	Micro-	Inter-	Endo-
Macro-	Milli-	-phobic	-azo	Bi- / di-
Omni-	Intra-	Exo-	Poly-	Halo-

Section 2 – Chemical Fundamentals

Chemists are always talking about the building blocks of the world such as atoms, molecules, elements and compounds.

The following series of images are representations of different particles. Choose the most appropriate phrase from the list below that you think the image represents.

Each shape represents the same type of atom *e.g.* all circles are one type of atom and all squares are another type of atom.

Answer phrases:

(1) - Atoms of an element

(2) - Molecules of an element

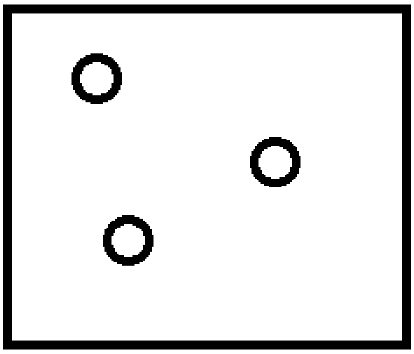
(3) - Molecules of a compound

(4) - Ions of an element

(5) - Mixture of molecules of different compounds

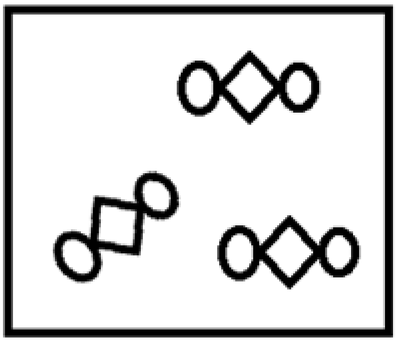
(6) - Mixture of atoms of different elements

(i)



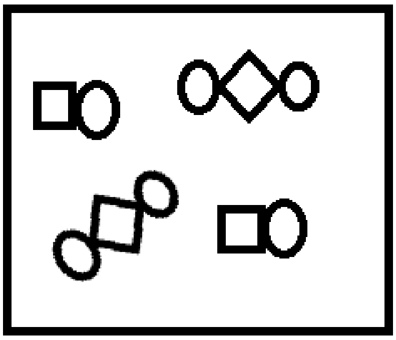
Represents (choose one of the six options) -

(ii)



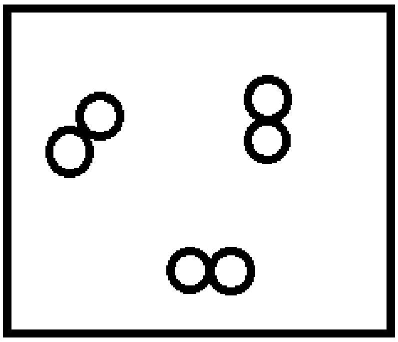
Represents –

(iii)



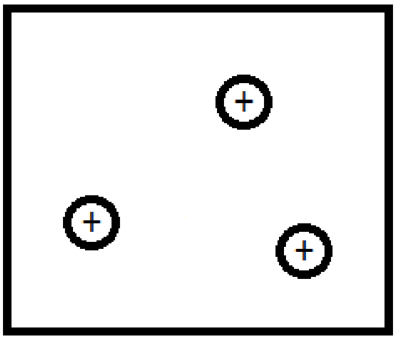
Represents –

(iv)



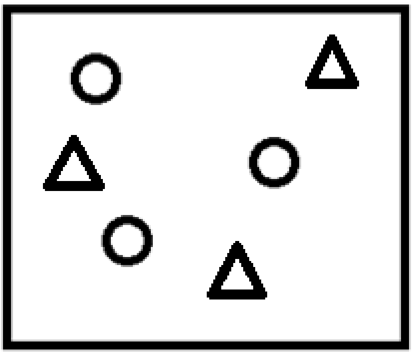
Represents -

(v)



Represents -

(vi)

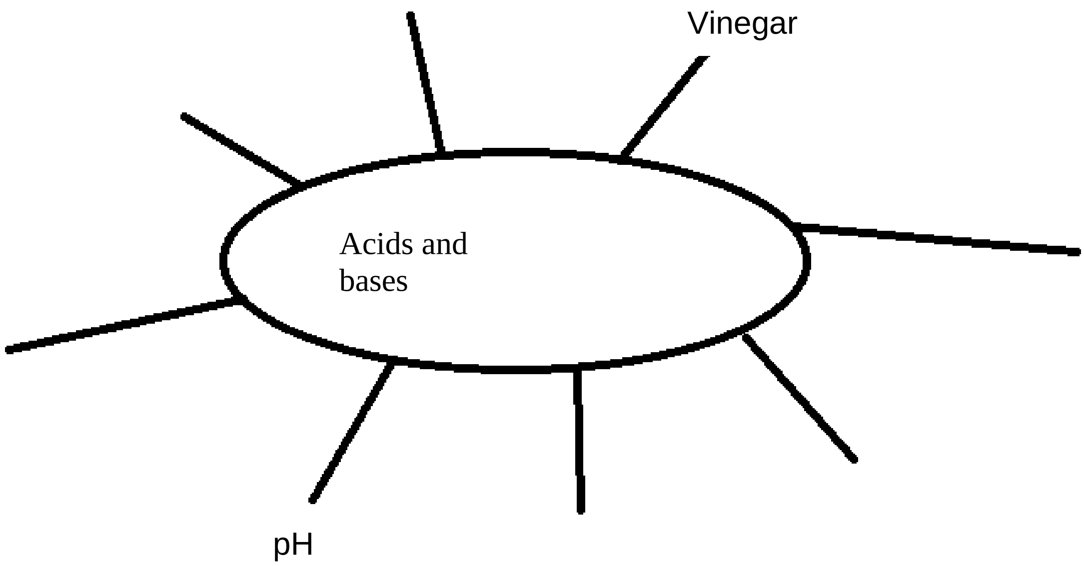


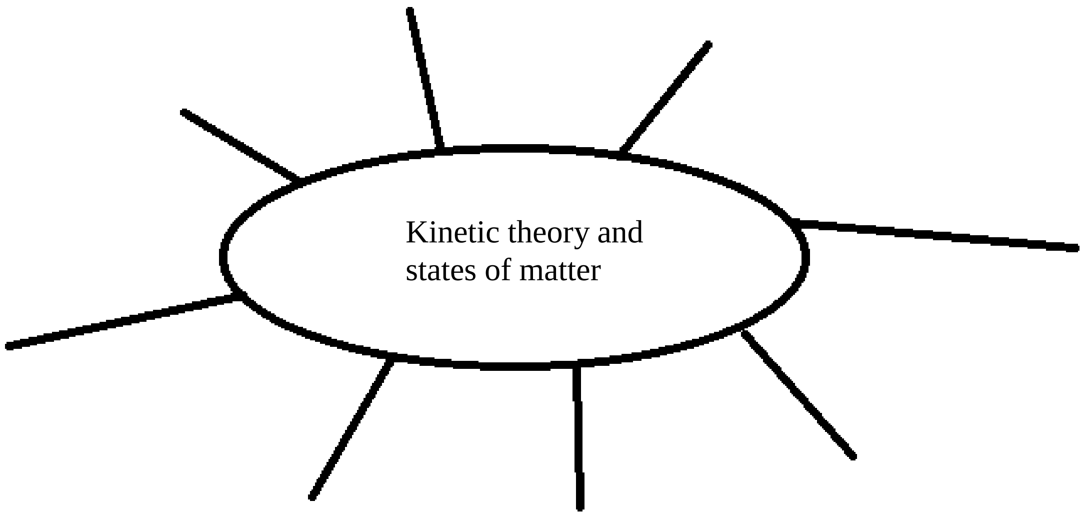
Represents -

Section 3 – Word families

No word exists in isolation but rather there are a series of associated words that are required to explain their meaning. For example, it is difficult to explain what a car is without talking about wheels, engines and metal.

For each of the following key topics add words to the spider diagram that may be related to it and important when discussing that topic. A couple of examples have been added to the first diagram. Add more lines and words if you can think of more!




Kinetic theory and
states of matter

Section 4 – Symbolic language.

Chemists use symbols to represent different things. For each of the questions below decide whether the pairs of symbols are equivalent (mean the same thing).

(i) H_2O and OH_2

Equivalent: Yes / No / don't know (circle your answer)

(ii) NaCl (aq) and NaCl (l)

Equivalent: Yes / No / don't know (circle your answer)

(iii) Co and CO

Equivalent: Yes / No / don't know (circle your answer)

(iv) C_2H_6 and CH_3CH_3

Equivalent: Yes / No / don't know (circle your answer)

(v) Br_2 and 2Br

Equivalent: Yes / No / don't know (circle your answer)

Section 5 – Non technical words in a scientific context.

There are some words in science that you may be familiar with in everyday life but their meaning when used in science may be different.

For each of the multiple choice questions below choose the answer that best fits as the definition of the highlighted word.

Example.

What is the meaning of the word "weight" in the following sentence.

*"A spring scale was used to measure the **weight** of the container"*

A. The mass of the container

B. The density of the container

C. The force due to gravity on the container

D. The volume of the container

(1) What is the meaning of the word "complex" in the following sentence.

*"The chemical reaction was **complex**".*

A. The reaction goes to completion.

B. The reaction is slow.

C. The reaction is simple.

D. The reaction has several stages.

(2) What is the meaning of the word "weak" in the following sentence.

*"A buffer is normally a mixture of a **weak** acid and its conjugate base"*

A. The acid partially dissociates.

B. The acid fully dissociates.

C. It is a dilute solution.

D. The attractions between the acid molecules are not strong.

(3) What is the meaning of the word "saturated" in the following sentence.

*"The gas was collected and bubbled through **saturated** calcium hydroxide solution"*

A. The calcium hydroxide had completely dissolved in the solution.

B. No more calcium hydroxide could be dissolved in the solution.

C. No more water could be added to the solution.

D. The calcium hydroxide had soaked up as much water as possible.

(4) What is the meaning of the word "reduction" in the following sentence.

*"Chlorophyll can participate in oxidation and **reduction** reactions"*

A. A substance gains electrons during a reaction.

B. A substance loses electrons during a reaction.

C. A substance loses mass during a reaction.

D. A substance breaks down in a reaction.

(5) What is meant by the word "contract" in the following sentence.

*"The graphene capillaries will expand and **contract** depending on the localised humidity"*

A. Become smaller.

B. Become larger.

C. Become narrower.

D. Become reduced in scope.

(6) What is the meaning of the word "solution" in the following sentence.

*"The more concentrated **solution** resulted in a faster reaction"*

A. A substance that dissolves in a liquid.

B. A mixture of a liquid and a dissolved solid.

C. A substance that dissolves a solid.

D. A suspension of a solid in a liquid.

(7) What is the meaning of the word “salt” in the following sentence.

*“Acids and bases react together to form a **salt** and water”*

A. An ionic compound consisting of two non-metals ions.

B. A chemical with a bitter taste.

C. a chemical used to preserve foods.

D. An ionic compound consisting of metal and non-metal ions.

(8) What is the meaning of the word “spontaneous” in the following sentence.

*“The two chemicals seemed to combine in a **spontaneous** reaction”*

A. The reaction was very quick.

B. The reaction was explosive.

C. The reaction, once started, increased vigorously.

D. The reaction happened by itself.

(9) What is the meaning of the word “neutral” in the following sentence.

*“The number of electrons is the same as the number of protons and therefore the atom is **neutral**”*

A. The atom is neither acid or alkaline.

B. The atom is unreactive.

C. The atom has no overall electronic charge.

D. The atom has a pH = 7.

(10) What is the meaning of the word “cell” in the following sentence.

*“The fuel **cell** generated electricity using oxygen and hydrogen”*

A. A system containing two electrodes in an electrolyte.

B. A self-sustaining unit of life.

C. A container for isolating a chemical reaction.

D. A single unit of a larger reaction system.

Section 5 – Word choice

The quality of a piece of written work can be greatly enhanced by the choice of words used. The use of more academic and scientific words can improve your writing style and its readability.

Replace the highlighted word or phrase in the following sentences with a more appropriate scientific word or phrase. For example;

- A **solid** formed in the solution in the test tube at the end of experiment.

- A **precipitate** formed in the solution in the test tube at the end of experiment.

(i) When calcium carbonate is heated to a high temperature it **breaks down** into calcium oxide and carbon dioxide.

(ii) Hydrochloric acid completely **splits** into hydrogen and chloride ions in solution.

(iii) The experiment **gave off heat**.

(iv) The gas produced was completely **unreactive**.

(v) A mixture of the oil and water forms two layers because the liquids **do not mix**.

(vi) Wax **does not dissolve** in water.

(vii) The first stage of the **making** of aspirin requires reflux apparatus.

(viii) The **burning** of a fuel produces carbon dioxide and water.

(ix) The reaction was **started** by the addition of a catalyst.

(x) The reaction **ended** when all the acid was used up.

That is the end of the quiz – thank you for completing it.

Appendix 17 – Interview Questions and Scenarios

Questions for initial interview

1) What were your expectations of coming to study at university?

2) Is the experience meeting your expectations?

3) Do you often come across words in lessons that you are unsure of the meaning of?

4) Have you made use of any of the resources to support language understanding?

Scientific scenarios

1) I breathe on to a cup containing a hot drink and my glasses steam up.

2) 10g of lead has fewer atoms in it than 10g of sodium.

Questions for subsequent interviews

1) What strategies have you developed to improve your understanding of scientific language?

2) Which resources have you found most useful?

3) Which teaching strategies have you found most useful?

Scientific scenarios

1) I breathe on to a cup containing a hot drink and my glasses steam up.

2) 10g of lead has fewer atoms in it than 10g of sodium.

3) Why does benzene require a catalyst to react with bromine water whereas cyclohexene and phenol do not?

Durham University
Foundation Centre

PARTICIPANT CONSENT FORM

Project title: FOCUS Diagnostics – the development of an online diagnostic and instructional toolkit to enhance student understanding of subject specific language.

Researcher's name Dr Simon Rees and Mrs Megan Bruce

- I have read the Project Information Sheet and the nature and purpose of the activity has been explained to me. I understand and agree to take part.
- I understand that I may withdraw from the activity at any stage and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential.
- I understand that I will be recorded during one to one discussions about the project.
- I understand that data will be stored electronically and will only be accessible to the researchers and myself. Data will be deleted 2 years after the end of the study.
- I understand that I may contact the researcher if I require further information about the research.
- I understand that I may contact the Research Ethics Coordinator of the Foundation Centre, Durham University (Alison McManus – alison.mcmanus@durham.ac.uk) if I wish to make a complaint relating to my involvement in the research.

Signed ………………………………………………………………………… (research participant)

Print name ………………………………………………………………… **Date** …………………………………

Durham University
Foundation Centre

PARTICIPANT INFORMATION SHEET

Project title: FOCUS Diagnostics – the development of an online diagnostic and instructional toolkit to enhance student understanding of subject specific language

Researchers' name Dr Simon Rees and Mrs Megan Bruce

This project aims to investigate student understanding of subject specific language and the development of teaching and learning strategies to enhance this. In particular, this project will develop a diagnostic tool that will enable students' to assess their understanding of different areas of subject specific language. The tool will be supported by a suite of self-study learning activities to develop understanding of subject specific language. The project team will be developing the assessment tool and asking students to trial and evaluate it during the academic year 2013/14.

The production of these resources will enable students to develop greater confidence in their understanding and use of technical vocabulary. This will lead to improved confidence and ability to participate appropriately in subject specific discourse and enhance student engagement. We are particularly interested in the use of these activities for international and non-traditional students for whom these issues can be particularly acute. These groups of students may experience the greatest difficulties engaging with the academic challenges of studying within H.E. in the U.K. and they are the principle focus of the work of Durham University's Foundation Centre.

The outcomes from this activity may be published as part of our ongoing research. **Your anonymity, however, will be preserved at all times**.

Appendix 19 – Ethics forms

Durham University Foundation Centre
STAFF Research Ethics and Data Protection Monitoring Form

Research involving humans by all academic and related Staff and Students in the Foundation Centre is subject to the standards set out in the Department Code of Practice on Research Ethics.

It is a requirement that **prior to the commencement of all funded or un-funded research proposals and/ or scholarship projects** that this form be completed and submitted to the Foundation Centre Research Ethics and Data Protection Sub-Committee. The Committee will be responsible for issuing certification that the research meets acceptable ethical standards and will, if necessary, require changes to the research methodology or reporting strategy.

A copy of the **research proposal** which details methods and reporting strategies must be attached and should be no longer than two typed A4 pages. In addition you should also attach the **participant information sheet and consent form you plan to use**. Please refer to the Foundation Centre Informed Consent and Data Protection Policy for details of what needs to be included.

Please send the signed application form and proposal to the Chair of the Foundation Centre Ethics and Data Protection Advisory Sub- Committee (Alison McManus, tel. (0191) 334 8343, e-mail: alison.mcmanus@durham.ac.uk).

Name: Simon Rees and Megan Bruce

Title of research project: FOCUS Diagnostics – the development of an online diagnostic and instructional toolkit to enhance student understanding of subject specific language

Questionnaire

		YES	NO	Details
	Have you consulted with peers within the Foundation Centre about this project?	Y		IF NOT, please discuss your ideas informally with colleagues as well as with the Chairs of the Ethical Review Sub-Committee, the Scholarship Committee and Scholarship Forum before proceeding.
1.	Does your research involve living human subjects?	Y		IF NOT, GO TO DECLARATION AT END
2.	Does your research involve only the analysis of large, secondary and anonymised datasets?		N	IF YES, GO TO DECLARATION AT END
3a	Will you give your informants a written summary of your research and its uses?	Y		If NO, please provide further details and go to 3b
3b	Will you give your informants a verbal summary of your research and its uses?	Y		If NO, please provide further details
3c	Will you ask your informants to sign a consent form?	Y		If NO, please provide further details
4.	Does your research involve covert surveillance (for example, participant observation)?		N	If YES, please provide further details.
5a	Will your information *automatically* be anonymised in your research?	Y		If NO, please provide further details and go to 5b
5b	IF NO			If NO, why not?

	Will you explicitly give *all* your informants the right to remain anonymous?			
6.	Will monitoring devices be used openly and only with the permission of informants?	Y		If NO, why not?
7.	Will your informants be provided with a summary of your research findings?	Y		If NO, why not?
8.	Will your research be available to informants and the general public without restrictions placed by sponsoring authorities?	Y		If NO, please provide further details
9.	Have you considered the implications of your research intervention on your informants?	Y		Please provide full details
10.	Are there any other ethical issues arising from your research?		N	If YES, please provide further details.

Further details

The students will experience a variety of teaching strategies during the course and the development of understanding will be assessed. They will be encouraged and challenged to develop strategies to improve their understanding of scientific terminology.

Continuation sheet YES/NO (delete as applicable)

Declaration

(1.) I have read the Durham University Principles for Data Protection available here: http://www.dur.ac.uk/data.protection/
(2.) I have read the Department's Code of Practice on Research Ethics and believe that my research complies fully with its precepts. I will not deviate from the methodology or reporting strategy without further permission from the Department's Research Ethics Committee.
(3.) I understand and agree that any changes to the project design will require the completion of a new Ethics and Data Protection form.

Signed …Simon Rees…………………………..Date:…27/03/2012…………

SUBMISSIONS WITHOUT A COPY OF THE RESEARCH PROPOSAL, INFORMED CONSENT FORM AND PARTICIPANT INFORMATION SHEET WILL NOT BE CONSIDERED.

Appendix 20 – DART Activity

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Read the article and then answer the following questions:

1) What does the phrase “fuel cells generate energy through electrochemical oxidation” mean?

2) Why is a fuel cell thought to be more efficient for producing electricity than burning the fuel?

3) Summarise the chemical processes that ultimately result in the production of electricity form hydrogen at this plant *i.e*. start with the electrolysis of brine.

4) Do you think this is an efficient process for the production of electricity from hydrogen?

Appendix 21 – Foundation chemistry course handbooks

Image copyright restricted

Core Foundation Chemistry

Aims

- To encourage students to develop confidence in their own abilities in a science subject.
- To develop students' learning skills.
- To introduce a basic bank of knowledge on which students can build either by the process of self-study or in further courses of directed study.
- To develop confidence in a laboratory situation.
- To introduce a range of equipment.
- To develop observational and interpretative skills.
- To develop a problem-solving approach.
- To develop scientific report-writing, data handling and critical evaluation.
- To develop confidence and ability in handling chemical calculations.

Content

- Atoms, molecules, elements and compounds.
- Elements of the Periodic Table.
- Atomic structure. electronic configurations.
- Atomic masses: mass spectroscopy.
- Bonding. bond polarity, electronegativity, Intermolecular forces including bonding Hydrogen bonding.
- Shapes of molecules.
- Structures of solids including diamond and graphite.
- Diffusion of gases and states of matter, gas, solid, liquid.
- Acids, bases, alkalis and indicators.
- Periodic Table: trends and patterns.
- Kinetics: collision theory, distribution of molecular energies, activation energy (qualitative), catalysis
- reversible reactions, equilibria.
- Thermodynamics: exothermic and endothermic reactions, energy level diagrams, Hess' Law, bond energy calculations.
- Fossil fuels, crude oil.
- Laboratory experiments covering the following subject areas: structure and bonding, empirical formulae by mass, acids and alkalis, metals, periodicity, kinetics, enthalpy changes, electrochemistry, organic chemistry.
- Calculations: relative atomic and molecular masses, formulae and equations, empirical formulae from mass and from unit cell, the mole, mass/mole, molar volume, volumetric calculations from titration results, simple treatment of Hess cycle, STP.

Learning Outcomes

Subject-specific Knowledge:

- By the end of the module students will have acquired the knowledge to be able to:
- describe atomic and electronic structure, for the first 20 elements.
- describe, with examples, different bonding types and the relation of bonding to properties and structures.
- identify characteristics of metals, non-metals, acids and alkalis.
- identify and explain the factors affecting rate of reaction.
- describe exothermic and endothermic reactions.
- describe states of matter, simple Kinetic Theory.

Subject-specific Skills:

- By the end of the module students will have acquired the skills to be able to:
- use the Periodic Table.
- work confidently and effectively in a laboratory, with due attention to safety.
- relate observations and data to underlying theory.
- write a scientific report with critical evaluation.
- select and use basic lab equipment.
- carry out chemical calculations as detailed on the syllabus.

Key Skills:

- By the end of the module the students will:
- be able to communicate effectively in writing.
- be able to apply number both in the tackling of numerical problems and in the collecting, recording, interpreting and presenting of data.
- be able to demonstrate problem solving skills.

Modes of Teaching, Learning and Assessment and how these contribute to the learning outcomes of the module

- Theory, initial concepts and techniques will be introduced during seminars, lectures, demonstrations and practicals/workshops.
- Much of the learning, understanding and consolidation will take place through the use of structured exercises during sessions and students own time.
- Knowledge and understanding of concepts will be assessed by two written laboratory reports and the written assessment.
- Knowledge and ability to use and apply concepts will be tested by the two tests.

Assessment

This course will be assessed by the following tasks:

Assessment	Weighting (%)
Assignment; part A – presentation (10%) and part B – structured questions (20%)	30
Laboratory report	10
Module test	60

Set work must be completed within the time allowed. Late work will not gain credit unless an extension has been granted in advance.

Online resources and communication

Course presentations and resources will be made available on DUO where there are also links to other useful websites. Course announcements may also be made on DUO and via email.

Support with scientific vocabulary can be accessed via the E-glossary at www.dur.ac.uk/foundation.science.

Reading

Any good A-level textbook will cover the core content of the course e.g.

Chemistry AS (Heinemann) ISBN 978 0 435691 81 3

Chemistry AS (Collins) ISBN 0 00 327753 4

You may also be interested in reading other relevant popular science books about the subject:

The Fly in the Cathedral by B. Cathcart

Atom by Piers Bizony

Nature's Builiding Blocks: An A-Z guide to the Elements by John Emsley

Or there are also several interesting chemistry magazines:

- Chemistry Review – available from the University library
- Chemistry World - http://www.rsc.org/chemistryworld/
- Education in Chemistry - http://www.rsc.org/eic/

And for those progressing to a chemistry degree you may consider looking at the following later in the year:

Chemistry by Housecroft and Constable
Foundations of inorganic chemistry by Winter and Andrew

Content Summary

This is a summary of the course content but the specific order may be different.

Section	Content
1	Elements, compounds, formulae and chemical reactions
2	Atomic Structure
3	Relative Atomic Mass and the Mole
4	Empirical Formulae
5	Ionic and covalent bonding
6	Metallic bonding and structures
7	Properties of ionic and covalent compounds
8	Shapes of molecules
9	Electron configurations
10	States of matter and intermolecular forces
11	The Periodic Table – groups and periodicity
12	Formulae from ions
13	Acids and bases
14	Moles, solutions and concentration
15	Titrations
16	Rates of reaction
17	Oxidation numbers and redox reactions
18	Reversible reactions and equilibria
19	Enthalpy – Hess's Law and bond enthalpies

Supporting Study resources

There is a wealth of resources available via the DUO site to support and extend your studies. The content for each week including any relevant powerpoint presentations can be found under the teaching material tab.

Within the language help section you can find links to the E-glossary which has been created by students to explain key chemistry words on the course (www.dur.ac.uk/foundation.science).

The FOCUS tool has also been developed to enable students to deepen their understanding of academic writing in science. It contains a searchable database of student texts from foundation to Ph.D. level (www.dur.ac.uk/foundation.focus).

Advanced Chemistry

Part A – Organic Chemistry

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Aims

- To encourage students to develop confidence in their own abilities in a science subject.

- To develop students' learning skills.
- To extend the fundamental knowledge base in Chemistry to include physical processes and organic chemistry.

Content

- fundamentals of organic chemistry.
- alkanes, alkenes.
- alkynes, alcohols, arenes.
- plastics.
- carbonyl compounds.
- carboxylic acids, esterification reaction.
- amines, amino acids, proteins, optical isomersion.
- chemical equilibria.
- thermodynamics.
- electrochemical cells.
- pH.
- ionic equations
- oxidation and reduction (including metal extraction)

Learning Outcomes

Subject-specific Knowledge:

- By the end of the module students will have acquired the knowledge to be able to:
- describe the structure and reactions of a range of homologous series.
- define enthalpy, entropy and free energy and their relationship.
- describe different types of isomerism in organic molecules, with examples.
- understand and use pH in a range of applications.

Key Skills:

- By the end of the module the students will:
- be able to communicate effectively in writing
- be able to apply number both in the tackling of numerical problems and in the collecting, recording, interpreting and presenting of data
- be able to demonstrate problem solving skills

Modes of Teaching, Learning and Assessment and how these contribute to the learning outcomes of the module

- Theory, initial concepts and techniques will be introduced during lectures and demonstrations.
- Much of the learning, understanding and consolidation will take place through the use of structured exercise during sessions and students own time.
- Knowledge understanding and ability to use and apply concepts will be tested by an end of module exam.

Summative Assessment

This course will be assessed by a single examination (2 hours):

Online resources and communication

Course presentations and resources will be made available on DUO where there are also links to other useful websites. Course announcements may also be made on DUO and via email.

Reading

Any good A-level textbook will cover the core content of the course *e.g.*

Chemistry AS (Heinemann) ISBN 978 0 435691 81 3

Chemistry AS (Collins) ISBN 0 00 327753 4

Chemistry A2 (Heinemann) ISBN 978 0 435691 98 1

Content Summary

This is a summary of the course content but the specific order may be different.

Section	Content
1	Alkanes, alkenes and alkynes
2	Arenes
3	Halogenoalkanes
4	Alcohols
5	Polymers
6	Carbonyls
7	Carboxylic acids and esters
8	Amines, amino acids and proteins
9	Electrochemistry
10	Hess's law and Born Haber cycles
11	Entropy and free energy
12	pH and K_a
13	The equilibrium constant - K_c

Core Foundation Chemistry
Module Assessment 1

Issue date:

Completion date:

Part A. Chemistry in Our Lives. (20 marks)

Produce a piece of work to describe and explain the significance of chemistry in our everyday lives. In particular, it should focus on the content of the Core Foundation Chemistry course.

The presentation can be in any of the following formats:

i) A powerpoint presentation (up to 10 slides).
ii) A piece of extended writing (up to 1000 words).
iii) A video or podcast (up to 5 minutes).

Use the following self-assessment questions to assist you in producing your piece of work.

1) Is the chemistry relevant to the content that has been covered during the first part of the Core Foundation Chemistry course?
2) Is the presentation style clear?
3) Have you referenced sources of information?

15 marks are available for the chemistry content and linking it to our everyday lives and 5 marks are available for the quality of the presentation and the referencing.

Core Foundation Chemistry
Module Assessment 1

Part B.

Attempt ALL of the following questions. (Total marks = 40)

Please write your answers legibly and indicate any sources used. Show all working.
Number clearly each section and sub-section of your answers.

Issue date: 14/11/2016
Completion date: 01/12/2016

1. Simple **Kinetic Theory of Matter** provides a model of matter in terms of the positions and movements of **particles** and of their energies.

Explain the following in terms of simple Kinetic Theory.
[6]

a) The changes that occur when a solid is heated until it melts.

b) It is easier to compress air than water.

c) A gas fills any container into which it is put and exerts a pressure on the container walls.

2. One definition of an element is:

'A substance that cannot be broken down into simpler substances by chemical methods'.

The table below shows some of the 'substances' which Lavoisier thought were elements divided into four groups. He published these groups in 1789.
The modern names of the 'substances' are given in brackets.

Acid-making elements	Gas-like elements	Metallic elements		Earthy elements
sulphur	light	cobalt	mercury	lime (calcium oxide)
phosphorus	caloric (heat)	copper	nickel	magnesia (magnesium oxide)
charcoal (carbon)	oxygen	gold	platina (platinum)	barytes (barium sulphate)
	azote (nitrogen)	iron	silver	argilla (aluminium oxide)
	hydrogen	lead	tin	silex (silicon dioxide)
		manganese	tungsten	

a) Define the term **compound** and name **two** substances in the list which are compounds.

b) Suggest why Lavoisier thought that these substances were elements.

c) Name one substance in the list which is **not** a chemical element or compound. [5]

3. In 1808, John Dalton put forward an atomic theory. It had evidence from careful chemical measurements and was not just a philosophy.

His theory stated that:

- All elements consist of atoms, which are extremely small, indivisible and indestructible particles.

- An element is pure because all atoms of the same element are exactly alike and, in particular, they have the same weight.

- The atoms of one element differ from the atoms of other elements *e.g*. having different masses.

- Atoms of different elements combine together in simple whole number ratios, such as 1:1, 2:1, 3:2, to form 'compound atoms'. The atoms are bound together by a force of attraction.

Although some of Dalton's ideas have been shown to be incorrect, his theory formed the basis for much of the work of 19^{th} century chemists, including the foundation of the Periodic Table.

a) How does Dalton's Atomic Theory differ from modern Atomic Theory? [5]

In your answer consider the following:

- are atoms indivisible and indestructible?
- are there subatomic particles? If so, what are they like?
- are the atoms of an element identical in all respects?
- what feature of an atom characterises a particular element?

b) What is the Periodic Table and why have chemists found it so useful? [5]

4. The element magnesium (atomic number 12) reacts with chlorine (17) to form magnesium chloride.

a) Draw diagrams to show the arrangements of <u>**all**</u> the electrons in a magnesium atom and a chlorine atom.

b) What happens to these electron arrangements when magnesium reacts to form magnesium chloride?

c) Explain why magnesium chloride only conducts electricity when melted or dissolved in water. [6]

5 a) With the aid of diagrams, describe the bonding and structure found in the following two elements;

- Copper
- Bromine.

[5]

b) The table below gives information about several substances, A to F.

Substance	Melting point ºC	Boiling point ºC	Electrical conductivity		
			When solid	When liquid	When dissolved in water
A	-39	357	good	good	does not dissolve
B	712	1418	poor	good	good
C	-25	144	poor	poor	does not dissolve
D	37	344	poor	poor	does not dissolve
E	1084	2570	good	good	does not dissolve
F	1610	2230	poor	poor	does not dissolve

Which of the substances A to F is:

(i) a metal which is a solid at room temperature (20ºC)
(ii) made of small molecules and is a liquid at room temperature (20ºC)
(iii) a giant covalent compound?
(iv) an ionic compound [4]

6. Explain the meaning of the following terms:

a) Relative Atomic Mass

b) The mole (as a unit for amount of substance)

[4]

FACTORS AFFECTING THE RATE OF REACTION

REACTION BETWEEN MARBLE CHIPS (Calcium Carbonate) AND HYDROCHLORIC ACID

$$CaCO_3\ (s) + 2HCl\ (aq) \rightarrow CaCl_2\ (aq) + CO_2\ (g) + H_2O\ (l)$$

The rate of a particular chemical reaction (how much product is formed/reactant is consumed in unit time) depends on a number of factors: concentration of reactants, temperature, catalysts, pressure and degree of subdivision of reactant.

When marble chips react with hydrochloric acid carbon dioxide is released. The gas that is evolved can be collected during the course of the reaction and the rate of reaction determined.

In this experiment you will study the effect on the rate of this reaction of changes in the concentration and temperature of the hydrochloric acid.

SAFETY: WEAR SAFETY GLASSES AT ALL TIMES

DILUTE HYDROCHLORIC ACID CORROSIVE, IRRITANT

Avoid skin contact and wash off any spills thoroughly with water

THE EFFECT OF CONCENTRATION ON RATE OF REACTION

The rate of reaction depends on the concentration of the reactants.
The rate of reaction is measured by the volume of gas produced at 1 minute intervals

1. Set up the apparatus as demonstrated.
2. Measure out 50cm^3 of 2 moldm^{-3} Hydrochloric acid and place it into a 250 cm^3 conical flask.
3. Measure out 2g of marble chips and add to the acid.
4. Immediately replace the bung and measure the volume of gas produced every minute for 5 minutes.
5. Make a solution of half the concentration and repeat.
6. Repeat this for a further three dilutions by halving the concentration each time.
7. Record your results in a table to show volume of gas produced each minute for five minutes for each of the five concentrations
8. Plot a graph of the results and calculate the initial rate of reaction (vol. of gas cm^3 sec^{-1}) for each concentration.

THE EFFECT OF TEMPERATURE ON RATE OF REACTION

1. Warm $50cm^3$ of an appropriate concentration of HCl (based on your results from the first experiment) to $30^{O}C$ and repeat the experiment as before.

2. Repeat the experiment at $40^{O}C$, $50^{O}C$, $60^{O}C$ (It does not have to be exactly this temperature).

3. Measure the temperature at the end of the experiment in order to determine the average temperature.

4. Record the results in a table with the temperature at the start and the end of the experiment and the volume of gas every minute for five minutes.

5. Plot a graph of the results and calculate the initial rate of reaction (vol. of gas $cm^3\ sec^{-1}$) for each temperature.

PLEASE NOTE:

The report for this experiment forms one of the Assignments for the Module.

Choose one of these experiments (the effect of concentration or the effect of temperature) for your laboratory report.
***Note*: You may wish to refer to results from the other experiment for comparison in your conclusion.**

COMPUTER GENERATED GRAPHS WILL NOT BE ACCEPTABLE

Please supply hand-drawn copies of each graph for the original report you have to submit (graphs may be scanned for the electronic copy)

Reports to be submitted by: 10 am Thursday 17th December

Requirements

chemicals	dilute hydrochloric acid (2 $moldm^{-3}$) marble chips
Apparatus	250 cm^3 conical flask Bung with delivery tube 100 cm^3 measuring cylinder x 2 Retort stand and clamp Large beaker / tub 25 cm^3 measuring cylinder 0-110 ^{O}C thermometer stop-clock Bunsen burner, tripod and gauze or hotplate. graph paper.

Core Foundation Chemistry – Practise paper

Time allowed: **3 hours**

Examination material provided: **Periodic Table**
Multiple choice answer grid for Section A

Instructions:

Section A (20 marks): Multiple choice Q 1 - 10
Answer ALL questions on the grid provided

Answer Sections B and C in the spaces provided.

Section B
(90 marks): Q 11- 21

Answer ALL the questions

Section C (40 marks): Q 22 - 24
Answer TWO of the three questions

You are *advised* to spend 20 minutes on Section A, 1 ¼ hours on Section B and 55 minutes on Section C. You may use approved calculators in this test.

SECTION A.
Answer ALL the questions in this section on the answer grid provided.
Mark the ONE answer which best fits the questions.
Each question carries two marks.

1. Which of the following substances in solution has a pH greater than 7?

A carbon dioxide
B salt
C lemon juice
D ammonia

2. Which of the following is a **strong** alkali?

A ammonia
B limewater
C sodium hydroxide
D sodium hydrogen carbonate

3. Which of the following is **not** a transition metal?

A copper
B iron
C silver
D tin

4. During the formation of a covalent bond, the atoms

A gain or lose electrons
B share electrons
C gain or lose protons
D share protons

5. The type of structure found in iodine is

A simple molecular
B giant covalent
C giant ionic
D giant metallic

6. Which of the following statements about carbon is **correct**?

A Diamond conducts electricity because it has delocalised electrons

B Diamond contains very strong bonds and is chemically inert
C Diamond and graphite are different isotopes of carbon
D In graphite each carbon atom is bonded ionically to 4 other carbon atoms

7. Elements in the Periodic Table are listed in order of increasing

A relative atomic masses
B mass number
C atomic number
D number of outer shell electrons

8. Which of the following equations is correctly balanced?

A $Zn + HCl \rightarrow ZnCl_2 + H_2$
B $2\ Na + H_2O \rightarrow 2\ NaOH + H_2$
C $4\ Al + 3\ O_2 \rightarrow 2\ Al_2O_3$
D $Na_2CO_3 + HNO_3 \rightarrow NaNO_3 + H_2O + CO_2$

9. In which of the following equations is the **first** reagent behaving as a Brønsted-Lowry acid?

A $HF + H_2O \rightarrow H_3O^+ + F^-$
B $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$
C $CH_3COOH + HCl \rightarrow CH_3COOH_2^+ + Cl^-$
D $H_2O + HCl \rightarrow H_3O^+ + Cl^-$

10. When excess zinc powder reacts with copper sulphate solution, which of the following changes does **not** take place?

A The mixture fizzes
B The mixture becomes hot
C A brown solid sinks to the bottom of the tube
D The blue solution becomes colourless

Section B
Answer all the questions in the spaces provided.
Q11-15 are laboratory calculations; Q 16-21 are on topics covered in lectures.

Use the relative atomic masses below for these calculations involving formulas and moles.

H=1 C=12 N=14 O=16 Mg=24 Al=27 S=32 Ca=40 Fe=56 Br=80

11. Name the following compounds: [3]

$CaBr_2$ …………………………………………………………………………………………..

NH_4NO_3 ……………………………………………………………………………….……..

$Fe_2(CO_3)_3$ ……………………………………………………………………….……………
.

12. Calculate the relative formula mass of the following compounds:

Aluminium sulphate $Al_2(SO_4)_3$

…………………………………………………………………………………………….…….

Glucose $C_6H_{12}O_6$

……………………………………………………………………………………………….…..

Calculate the % by mass of carbon in glucose.

…………………………………………………………………………………………….…….

…………………………………………………………………………………………..…… [4]

13. Calculate the number of moles contained in

0.6g magnesium atoms …………………………………………………………………….....

3.5g nitrogen molecules …..

.... [3]

How many atoms are there in one molecule of aluminium sulphate $Al_2(SO_4)_3$?

……………………………………………………….…………………………………… [1]

14. Methane CH_4 burns with excess oxygen to produce carbon dioxide and water.

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$$

Calculate the mass of water produced from 3.5g of methane.

……………………………………………………………………………………………….....

……………………………………………………………………………………………..…..

……………………………………………………………………………………………….....

…………………………………………………………………………………………………

……………………………………………………………………………………………… [4]

15. A compound X contains by mass 16.2% magnesium, 18.9% nitrogen and also oxygen.

State what is meant by the empirical formula.

…………………………………………………………………………………………………

……………………………………………………………………………………………… [1]

Calculate the empirical formula of X. (Mg = 24, N = 14, O = 16)

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………… [3]

16. Complete the following table.

Particle	Relative charge	Relative mass
Proton		
Neutron		
electron		

[3]

What is meant by the term **isotopes**?

……

…………………………………………………………………………………………………….… [2]

An atom contains one more proton than, but the same number of neutrons as, an atom of ^{36}S.
Give the mass number and atomic number of this atom and use your Periodic Table to identify the element

…………………………………………………………………………………………….…… [2]

Give the electron configurations of

a magnesium atom……………………………………………………………………..……….

an oxygen atom .... [2]

Magnesium and oxygen react together to form the ionic compound magnesium oxide.
Write an equation for this reaction.

……………………………………………………………………………………………………. [2]

Explain how each of the ions in this compound is formed.

……………………………………………………………………………………………………..….

……………………………………………………………………………………………………. [2]

Draw a dot and cross diagram to show the bonding between a sodium and chlorine atom.

[2]

How are the ions held together in solid sodium chloride?

………………………………………………………………………………………………………..…

…………………………………………………………………………………………………….. [1]

Why do ionic compounds tend to have high melting points.

……………………………………………………………………………………………..….

…………………………………………………………………………………………….. [2]

Draw a dot and cross diagram to show the bonding in hydrogen bromide.

[2]

What type of bonding is this and give two physical properties you would expect this compound to have?

………………………………………………………………………………………………

………………………………………………………………………………………………

…………………………………………………………………………………………… [3]

17. Citric acid is a **weak** acid found in oranges and lemons.
What is meant by the term weak when applied to acids?

………………………………………………………………………………………………[1]

How are an acid and a base defined by the Bronsted-Lowry theory?

………………………………………………………………………………………………

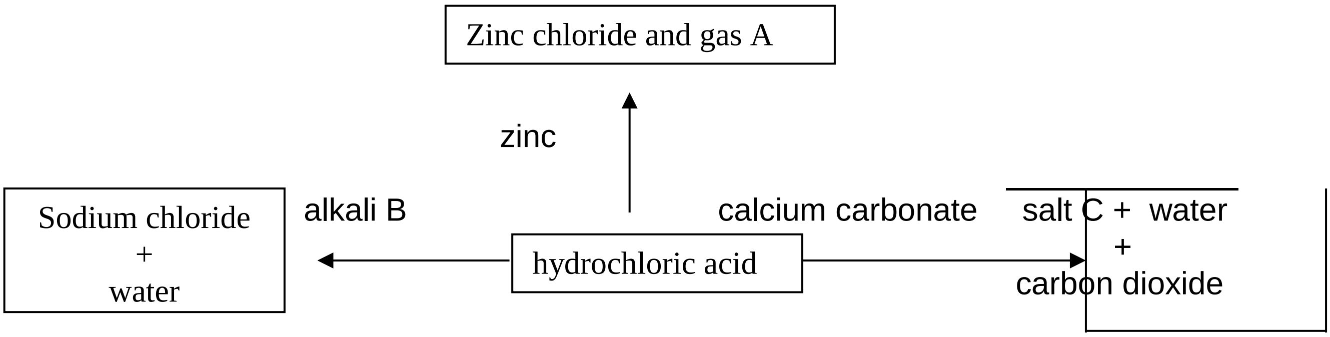
…………………………………………………………………………………………… [2]

Describe and give the results of a test which would show that citric acid is a weaker acid than hydrochloric acid.

Test ……………………………………………………………………………………...

Results…………………………………………………………………………………. [2]

The flow diagram shows some reactions of hydrochloric acid.



Give the name of

gas A ……………………………………………………………………………………….

alkali B ……………………………………………………………………………………..

salt C ……………………………………………………………………………………… [3]

Describe a chemical test for carbon dioxide. State what you would use and the result.

……………………………………………………………………………………………..… [2]

Three bottles are known to contain the following substances

dilute hydrochloric acid **limewater** **distilled water**

Unfortunately, the labels have come off the bottles!
Describe the chemical tests you would need to do in order to identify which of these substances each bottle contains. State what you would observe.
There are several possible ways of doing this **safely**; only one scheme is needed. [4]

………………………………………………………………………………………………

……………………………………………………………………………………………..
.
……………………………………………………………………………………………..

……………………………………………………………………………………………..

18. Using your Periodic Table, **name** an element which is:

in Group 3 ……………………………………………………………………………...

a gas ……………………………………………………………………………………...

the most reactive halogen …………………………………………………….…….

a non-metal in period 2 ………………………………………………………….. [4]

Metals conduct electricity, non-metals (except graphite) do not. Give two other ways in which metals are different from non-metals.

…………………………………………………………………………………………………

…………………………………………………………………………………………… [2]

Explain why the atomic radius of the elements Na to Cl decreases across Period 3.

Explanation ……………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………… [2]

Explain, in terms of atomic structure, why elements in the same group of the modern Periodic table have similar chemical properties.

…………………………………………………………………………………………………… [1]

Below is part of Mendeleev's Periodic Table published in 1869.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Period 1	H						
Period 2	Li	Be	B	C	N	O	F
Period 3	Na	Mg	Al	Si	P	S	Cl
Period 4	K Cu	Ca Zn	* *	Ti *	V As	Cr Se	Mn Br

Use this table and the 'modern' Periodic Table provided to answer these questions.
Name one element in Group 1 of Mendeleev's Table which are **not** found in Group 1 of the modern Periodic Table.

……………………………………………………………… [1]

Which group of elements in the modern Periodic Table is missing on Mendeleev's table?

…………………………………………………………………………………………………… [1]

Mendeleev left several gaps on his Periodic Table. These gaps are shown as asterisks (*) on the table above. Suggest why Mendeleev left these gaps.

…………………………………………………………………………………………………….. [1]

19. Place the following metals in order of reactivity with acids (most reactive first):
aluminium iron lead magnesium zinc

……………………………………………………………………………………………………[1]

Name a metal which will not react with dilute acids.

……………………………………………………………………………………………………[1]

Balance the equation for the reaction.

$Mg + ---- HNO_3 \rightarrow Mg(NO_3)_2 + ---- H_2O + 2\ NO_2$ [1]

More than ten years ago, an accident occurred in a factory in the Midlands. Workers were evacuated when a toxic gas filled the building. It happened when nitric acid spilled onto the floor and mixed with magnesium metal powder.

Explain, in terms of particles, how the gas was able to fill the factory quickly.

……………………………………………………………………………………………………..

…………………………………………………………………………………………………… [2]

The reaction with metal **powder** is more dangerous than if the acid had fallen onto the same mass of metal **bars**. Explain why.

…………………………………………………………………………………………………….. [1]

Water was sprayed on the metal and acid to slow down the reaction.
Explain, in terms of particles, why the reaction would slow down.

……………………………………………………………………………………………………..

…………………………………………………………………………………………………. [2]

20. Define the term activation energy.

……………………………………………………………………………………………… [1]

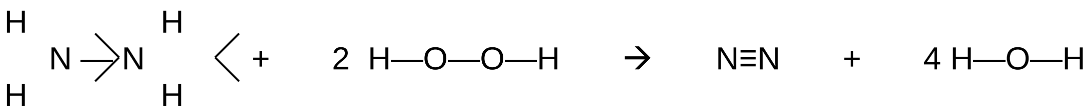
What is the meaning of the term mean bond enthalpy?

……………………………………………………………………………………………… [2]

Some mean bond enthalpies are given below.

Bond	N—H	N—N	N≡N	H—O	O—O
Mean bond enthalpy/ kJ mol^{-1}	388	163	944	463	146

Use the values in the table to calculate the overall enthalpy(energy) change for the reaction shown below. [4]



………………………………………………………………………………………………....

………………………………………………………………………………………………

………………………………………………………………………………………………...

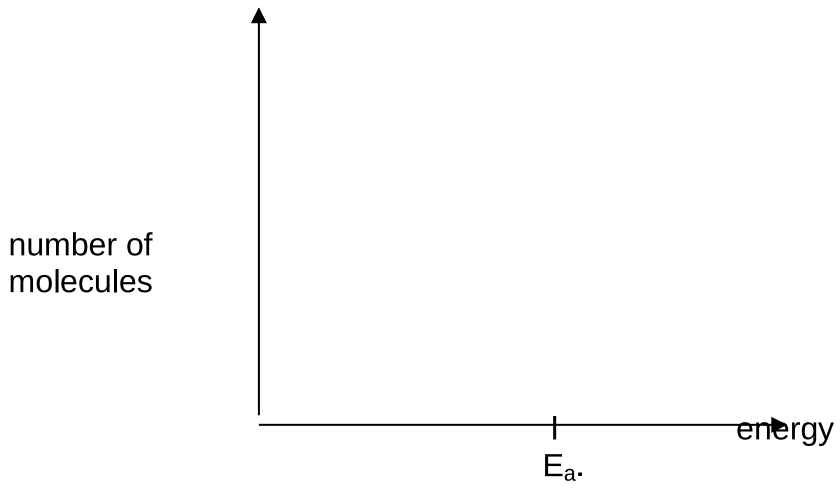
………………………………………………………………………………………………..

This reaction is exothermic. Explain, by reference to your calculation, how you know.

……………………………………………………………………………………………… [1]

21. Draw, on the axes below, a Maxwell-Boltzmann energy distribution curve for a sample of gas in which only a small proportion of molecules have energy greater than the activation energy, E_a.
[2]

Then, on the same axes, draw a second curve to show the distribution of energies at a higher temperature, T_H, and label the curve T_H. [3]



State the effect, if any, of adding a catalyst on the rate at which the gas decomposes. Explain how a catalyst has this effect.

Effect on rate……………………………………………………………………………………..…….

Explanation ……………………………………………………………………………………………..

………………………………………………………………………………………………………. [3]

In terms of the behaviour of molecules, state what must happen before the gas molecules can react to form products.

………

……………………………………………………………………………………………………….. [2]

Section C
Answer TWO of the three questions 22 –24 in the spaces provided.
Each question carries 20 marks.

22. Describe the motion of particles in solid iodine and in iodine vapour. [3]

motion in solid iodine ………………………………………………………………………....

…………………………………………………………………………………………………

motion in iodine vapour………………………………………………………………………..

…………………………………………………………………………………………………

Explain why solid iodine vaporises when warmed gently.

……………………………………………………………….. ..……………………………………..

……………………………………………………………………………………………………[2]

Which one of the elements **aluminium, silicon** and **chlorine** has the lowest melting point?
Explain your answer in terms of the structure and bonding in that element. [3]

Element with lowest melting point ……………………………………………………………...

Explanation …………………………………………………………………………………..

…………………………………………………………………………………………………

…………………………………………………………………………………………..………

In terms of structure and bonding, explain why

diamond has a very high melting point ……………………………………………….…….

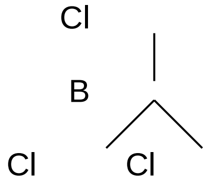
……………………………………………………………………………………………. [2]

graphite is soft ……………………………………………………………………………..

………………………………………………………………………………………………..[2]

Q22 continued

Shapes of molecules:



This diagram shows the shape of a boron trichloride molecule, BCl_3

Why is each bond angle exactly 120° in BCl_3?

……………………………………………………………………………………………….……..

………………………………………………………………………………………………. [2]

Give the name which describes the shape of molecules having bond angles of 109.5°.

………………………………………………………………………………………………. [1]

Give an example of one such molecule. …………………………………………………… [1]

Name the shape of the molecule with the formula SF_6.

……………………………………………………………………………………………….. [1]

Draw a sketch to show the shape of the H_2O molecule. Include any lone pairs of electrons and give the bond angle.

[3]

23. Fossil fuels, like (crude) oil and natural gas, are a source of chemicals and energy.

Crude oil, a mixture of hydrocarbons, is separated into fractions by fractional distillation. What is meant by the term **hydrocarbon**?

…………………………………………………………………………………………………….. [1]

Explain how the different fractions are separated by fractional distillation.

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….. [3]

What is catalytic cracking?

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

………………………………………………………………………………………………… [2]

Why is it carried out?

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

……………………………………………………………………………………………………. [2]

Petrol (octane) is used as a fuel in cars. Explain the role of the catalytic converter in the exhausts of cars to reduce pollution.

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….. [2]

Compounds and elements can be detected and analysed in a mass spectrometer.
Describe how, in a mass spectrometer, ions are

formed ……………………………………………………………………………………….

……………………………………………………………………………………………..

accelerated ………………………………………………………………………………….

……………………………………………………………………………………………..

separated ……………………………………………………………………………………

…………………………………………………………………………………………….. [6]

The table below gives the % abundance of each isotope of an element Z.

m/z	188	189	190	192
% abundance	13.0	21.8	26.1	39.1

Use the data above to calculate the relative atomic mass of Z. Give your answer to one decimal place.

…………………………………………………………………………………………………...

…………………………………………………………………………………………………...

………………………………………………………………………………………………. [3]

Deduce the identity of Z. ……………………………………………………………………. [1]

24. When nitrogen reacts with oxygen, a dynamic equilibrium is established.

$2\,NO(g) + O_2(g) \rightleftharpoons IO_2(g) \quad \Delta H^{\theta} = -115\ kJ\ mol^{-1}$

State what is meant by dynamic equilibrium.

……………………………………………………………………………………………………

……………………………………………………………………………………………………[2]

State and explain how the total pressure in this equilibrium reaction should be changed to give a higher yield of NO_2

Pressure change….……………………………………………………………………………

Explanation ……………………………………………………………………………………

……………………………………………………………………………………………... [3]

State and explain the effect of an increase in temperature on the yield of NO_2 in this equilibrium reaction.

Effect ……………………………………………………………………………………………

Explanation ……………………………………………………………………………………..

……………………………………………………………………………………………….. [3]

Ammonia is produced in the Haber Process as shown below.

$N_2(g) + 3 H_2(g) \rightleftharpoons H_3(g)$ exothermic

The reaction is reversible. What does this mean?

……………………………………………………………………………………………... [1]

Name the catalyst is used. …..……………………………………………………………… [1]

Q24 continued
A 70% equilibrium yield of ammonia is obtained at a temperature of 350°C and a pressure of 40MPa.
Explain why an industrialist may choose to operate the chemical plant at

a temperature higher than 350°C ……………………………………………………………..

a pressure lower than 40MPa……………………………………………………………… [2]

Molecules of CH_4, NH_3 and HF contain covalent bonds. In NH_3 and HF these bonds are also polar.
State what is meant by a

covalent bond ……………………………………………………………………………….....

polar bond …………………………………………………………………………………… [2]

Draw bonding diagrams of a methane molecule CH_4 and an ammonia molecule NH_3.
Label any lone pairs of electrons.

methane ammonia

[4]

Explain why the HF bond is polar.

………………………………………………………………………………………………….. [1]

The boiling points of NH_3, H_2O and HF are all high for molecules of their size.
What type of **intermolecular** force responsible for this property.

…………………………………………………………………………………………………. [1]

THE END

EXAMINATION PAPER

session	date	exam code

description

ANONYMOUS NUMBER: ……………………………………………………………………..

Time allowed: 2 hours

Examination material provided: Periodic Table
Multiple Choice Answer Grid for Section A

ANSWER BOOKLETS SHOULD <u>NOT</u> BE PROVIDED WITH THIS PAPER

Instructions: **Section A: Multiple Choice – 10 questions**
Answer ALL questions on the grid provided
[20 marks]

Answer Section B questions in the spaces provided. [80 marks]

You are advised to spend no more than 25 minutes on Section A,
You may use a Foundation Centre approved calculator in this exam.
Remember to show all working in calculations.

SECTION A

Answer <u>ALL</u> the questions in this section on the answer grid provided.
Mark the <u>ONE</u> answer that best fits the question.
Each question carries 2 marks.

1. Listed below are the electronic configurations of 4 elements. Which one of the configurations is incorrect?

A $1s^2 2s^2 2p^6 3s^1$
B $1s^2 2s^2 2p^6 3s^2 3p^6$
C $1s^2 2s^2 2p^6 3s^1 3p^5$
D $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$

2. Complete this sentence:

An endothermic reaction can spontaneously occur at a given temperature when

A The increase in entropy is greater than the enthalpy change
B The increase in entropy is less than the enthalpy change
C The decrease in entropy is greater than the enthalpy change
D The decrease in entropy is less than the enthalpy change

3. What type of mechanism is the reaction between benzene and chlorine an example of?

A Nucleophilic substitution
B Electrophilic addition
C Free radical substitution
D Electrophilic substitution

4. The general formula of C_nH_{2n} represents

A An alkane
B An alkene
C An alkyne
D An alcohol

5. Which one of the following statements is **incorrect** about this chemical reaction?

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

A An increase in pressure will increase the yield of sulphur trioxide.
B This reaction results in a decrease in entropy.
C ΔS is positive for this reaction.
D Increasing the concentration of sulphur dioxide would shift the equilibrium to the right.

6. Which of the following is the correct equation for the 1st electron affinity of bromine?

A $Br(l) + e^- \rightarrow Br^-(g)$
B $Br(g) + e^- \rightarrow Br^-(g)$
C $Br_2(g) + 2e^- \rightarrow 2Br^-(g)$
D $2Br(g) + 2e^- \rightarrow 2Br^-(g)$.

7. Which of the following statements could be true for an aqueous solution of hydrofluoric acid

A $[H^+] = [OH^-]$
B $[H^+] > [OH^-]$
C $[H^+] < [OH^-]$
D Only H^+ ions are present

8. What is the compound produced when butan-2-ol is oxidised?

A Butan-2-al
B Butanoic acid
C Butanoate
D Butan-2-one

9. What observation would be made if acidified potassium dichromate is heated with a secondary alcohol?

A The solution goes colourless.
B The solution turns from orange to green.
C A silver mirror forms.
D An orange precipitate forms.

10. What is $[H^+]$ for a solution with pH = 12.5?

A 3.2×10^{-13}
B 3.2×10^{-12}
C 2.3×10^{-13}
D 2.3×10^{-12}

exam code

SECTION B

Answer ALL questions in this section (11-21) in the spaces provided.

11. Catalytic cracking converts long chain alkanes in to a mixture of short chain alkanes and alkenes.

(a) Why is this process carried out?

……………………………………………………………………………………………………

…………………………………………………………………………………………………… **[1]**

(b) One of the products this reaction is ethene.

(i) What is the empirical formula of ethene?

…………………………………………………………………………………………….. **[1]**

(ii) What is the functional group present in ethene?

…………………………………………………………………………………………………… **[1]**

(iii) Describe a simple chemical test to detect the presence of ethene.

……………………………………………………………………………………………………

…………………………………………………………………………………………………….. **[2]**

(iv) What type of reaction is this an example of?

…………………………………………………………………………………………………….. **[1]**

(c) (i) State how ethene can be converted to ethanol.

……………………………………………………………………………………………………

…………………………………………………………………………………………………….. **[2]**

(ii) What is one advantage of producing ethanol by this method compared to fermentation?

…………………………………………………………………………………………………….. **[1]**

(d) (i) The ethanol was refluxed with acidified potassium dichromate. State any observations that would be made and the product of this reaction.

Observations:
……………………………………………………………………………………………………

…………………………………………………………………………………………….. **[1]**

Product: ……………………………………………………………………………………… **[1]**

(ii) State one important practical consideration to be aware of when undertaking a reaction under reflux.

……………………………………………………………………………………………… **[1]**

[Total = 12]

12. Methane reacts with chlorine to give chloromethane and a mixture of other organic products

a) What would be suitable reaction conditions for this to occur?

……………………………………………………………………………………………………

……………………………………………………………………………………………… **[1]**

b) Write an overall equation for this reaction.

……………………………………………………………………………………………………

…………………………………………………………………………………………….. **[1]**

c) Write equations to show the three stages to this reaction.

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……………………………………………………………………………………………… **[4]**

d) Explain why a mixture of organic products is obtained.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

………………………………………………………………………………………………… **[1]**

[Total = 7]

13. The table below shows the enthalpy changes that are needed to determine the lattice enthalpy of sodium oxide.

letter	Enthalpy Change	Energy / $KJmol^{-1}$
A	1st electron affinity of oxygen	-141
B	2nd electron affinity of oxygen	+790
C	1st ionisation energy of sodium	+496
D	Atomisation of oxygen	+249
E	Atomisation of sodium	+108
F	Formation of sodium oxide	-414
G	Latttice enthalpy of sodium oxide	

a) Define the term *lattice enthalpy*.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

………………………………………………………………………………………………… **[2]**

b) On the cycle below, write the correct letter in each empty box.

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[3]

c) Use the Born-Haber cycle to calculate the lattice enthalpy of sodium oxide.

Answer = ……………………………… $KJmol^{-1}$ **[2]**

d) Would you expect the lattice enthalpy for potassium oxide to be more or less exothermic than sodium oxide?
Explain why.

…………………………………………………………………………………………………..

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…………………………………………………………………………………………………. **[3]**

[Total = 10]

14. Biofuels such as bioethanol and biodiesel are increasingly being used as an alternative to fossil fuels to provide energy.

(a) Describe, with the aid of an equation, how bioethanol is manufactured by fermentation.

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.... **[3]**

(b) Biodiesel is obtained from plant oils. The manufacture involves several stages, all of which have a high energy requirement.

(i) Construct an equation to show the complete combustion of biodiesel.
Assume that the molecular formula of the biodiesel is $C_{15}H_{30}O_2$.

.... **[2]**

(ii) Many scientists suggest that society should use more biofuels rather than fossil fuels to provide energy. Suggest one advantage and one disadvantage of using more biofuels.

....

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....**[2]**

exam code

(c) Unsaturated compounds in plant oils can also be used to make margarine.

Describe how.

....

....

....

.... **[2]**

(d) Part of the structure of an unsaturated compound in plant oils is shown below:
$–CH_2CH_2CH{=}CHCH_2CH_2–$

(i) Draw the displayed formula of the *Z* isomer of this part of the structure.

[1]

(ii) Explain why this part of the structure can have an *E* and a *Z* isomer.

....

....

....

.... **[2]**

[Total = 12]

15. Methanol can be manufactured from carbon monoxide (CO) and hydrogen (H_2).

A dynamic equilibrium was set up in a 2.0 dm^3 sealed vessel as shown by the equation below.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

(a) State and explain the effect on the yield of methanol if the pressure is increased.

Effect on yield ……………………………………………………………………………………..

Explanation ………………………………………………………………………………………..

……………………..…………………………………………………………………………………..

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……………………………………………………………………………………………………... **[3]**

(b) State two characteristics of a system that is in *dynamic equilibrium*

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…….………………………………………………………………………………………………………

…….………………………………………………………………………………………………………

……..……………………………………………………………………………………………… **[2]**

The number of moles of each component at equilibrium is shown below

component	CO(g)	H_2(g)	CH_3OH(g)
Number of moles at equilibrium	6.20×10^{-3}	4.80×10^{-2}	5.20×10^{-5}

(c) Write an expression for K_C for this equilibrium system.

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……..………………………………………………………………………………………….…… **[1]**

(d) Calculate the value of K_C and state its units.

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………

…………………………………………………………………………………………………… **[3]**

Units…………………………………………………………………………………………… **[1]**

(e) The temperature was increased whilst keeping the pressure constant. The mixture was left to reach equilibrium.

The value for K_c decreased.

(i) Explain what happened to the equilibrium position.

………

…………………………………………………………………………………………………… **[1]**

(ii) Deduce the sign of the enthalpy change for the forward reaction. Explain your reasoning.

………

…………………………………………………………………………………………………… **[1]**

[Total = 12]

16. A student carries out an investigation based on the redox systems shown below

	Redox system	$E^{\ominus}$/V
1	$Ni^{2+}_{(aq)} + 2e^- \leftrightarrow Ni_{(s)}$	- 0.25
2	$Fe^{3+}_{(aq)} + e^- \leftrightarrow Fe^{2+}_{(aq)}$	+ 0.77
3	$Cr^{3+}_{(aq)} \leftrightarrow Cr_{(s)}$	- 0.74

The student sets up a standard cell to measure the standard cell potential using redox systems 1 and 2.

exam code

(a) Draw a diagram of this cell working under standard conditions.

[3]

(b) Write the overall cell equation for the reaction taking place in this circuit.

……………………………………………………………………………………..……………………

…..…………………………………………………………………………………………………… **[1]**

(c) Calculate the standard cell potential of this cell.

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……………………………………………………………………………………………………... **[1]**

(d) The student predicted that if a piece of nickel was placed in an aqueous solution of chromium (Cr^{3+}) ions there would be a reaction.
Explain whether you agree or disagree with this statement.

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……………………………………………………………………………………………………… **[3]**

[Total = 8]

exam code

17. This question is about acids and bases.

Nitric acid, HNO_3, is a strong Bronsted-Lowry acid.
Nitrous acid, HNO_2, is a weak Bronsted-Lowry acid with a K_a value of 4.43×10^{-4} mol dm^{-3}.

(a) Describe a simple laboratory test that would enable you to distinguish between these two acids.

………

………

…………………………………………………………………………………………………….. **[2]**

(b) What is the difference between a strong and weak acid?

………**[1]**

(c) What is the expression for the acid dissociation constant, K_a, of nitrous acid, HNO_2?

………

………

…………………………………………………………………………………………………….. **[1]**

(d) Calculate the pH of a 0.375 M (mol dm^{-3}) solution of nitrous acid, HNO_2.

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…………………………………………………………………………………………………….. **[3]**

[Total = 7]

18. The most common bulletproof material is Kevlar, a man made polymer similar to nylon which can be made into strong, extremely high-melting fibre that is five times stronger than steel.
A section of the polymer is shown below.

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(a) Draw the structure of the monomers required to construct this polymer.

[2]

(b) In a further experiment, a scientist reacted one of these monomers with ethanediol ($HOCH_2CH_2OH$) to make a new polymer.

(i) Which of the monomer units would react with ethanediol?

……………………………………………………………………………………………………….

……………………………………………………………………………………………………... **[1]**

(ii) What would be the repeating unit for this new polymer?

[2]

(iii) This new polymer was not as strong as Kevlar. Suggest a reason for this.

…….

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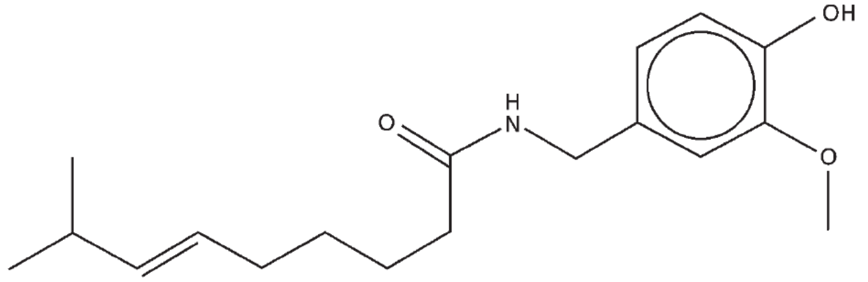
………... **[1]**

[Total = 6]

19. Chilli peppers are used to spice up many food recipes. They cause a hot burning sensation in the mouth which is not removed by drinking lots of water. Chemists have identified a group of compounds that cause this sensation – they are called Capsaicinoids.

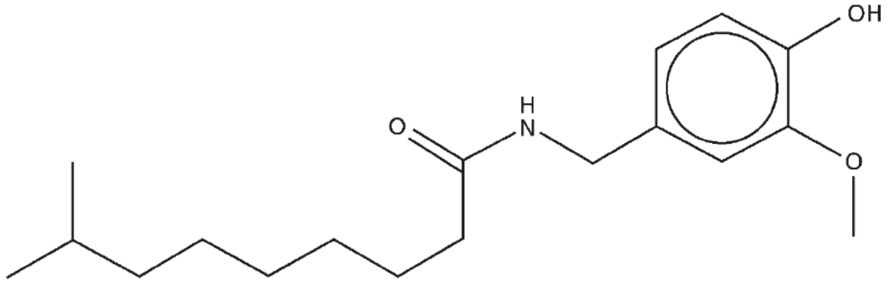
Two examples, Capsaicin and Dihydrocapsaicin are shown below.

Capsaicin



Capsaicin

Dihydrocapsaicin



Dihydrocapsaicin

(a) How many carbon atoms are present in Capsaicin?

………... **[1]**

exam code

(b) Which of these two compounds would you expect to form a clear colourless solution when reacted with bromine water? Explain why.

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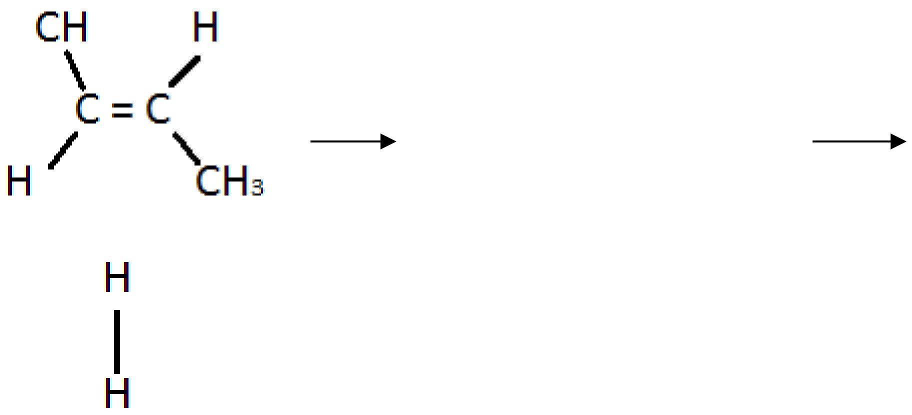
………**[2]**

(c) Identify and name one functional group present in either of these compounds.

…………………………………………………………………………………………………… **[1]**

(d) Capsaicin can be converted to dihydrocapsaicin by the electrophilic addition of hydrogen. Complete the mechanism below containing the relevant section of the capsaicin molecule to show this conversion.



[2]

[Total = 6]

THE END

Appendix 23 – Publications