



# The Development of Chemical Language Usage by “Non-traditional” Students: the Interlanguage Analogy

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## Abstract

Students commonly find specialist scientific language problematic. This study investigated developments in chemical language usage by six *non-traditional* students over the course of 1 to 4 years. The students participated in semi-structured interviews and were asked to explain specific chemical scenarios. Interviews were transcribed and analysed for the correct use of macroscopic and sub-microscopic scientific language and occurrences of interlanguage. Results indicate that students experienced difficulties incorporating sub-microscopic language into their explanations. Students also demonstrated *potential* chemical interlanguage, which we characterise as transitioning from vague to defined use, combining everyday and scientific language, interchanging terms and omission of terms and formulaic phrases. Implications of these findings are discussed in relation to science pedagogy.

**Keywords** Chemical language · Interlanguage · Non-traditional students · Science education

## Introduction

The central importance of language in science teaching and learning is well established (Carlsen 2007; Lemke 1990; Markic and Childs 2016; Wellington and Osborne 2001). Greater significance has been placed on language in international standards for science education in recent years (Lee et al. 2013). Learning science requires students to develop linguistic competence to participate in subject-specific discourse and engage in the social language of science using specific vocabulary (Mortimer and Scott 2003). This vocabulary presents many challenges, such as words which have different and specific meanings in science compared to everyday contexts or have multiple meanings (Cassels and Johnstone 1985; Gardner 1972; Rees et al. 2018a). Vygotsky’s perspective on development and learning occurring in social

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contexts (Vygotsky 1962) recognised that language development and conceptual development are inextricably linked. Byrne et al. (1994) state, difficulty with language causes difficulty with reasoning. In this study, scientific language relates to words used to explain natural phenomena in a chemical context. These challenges are significant for all science students but become even more valuable to understand from a pedagogical perspective as student populations become increasingly culturally and linguistically diverse and varied in prior knowledge levels (Cink and Song 2016). Non-traditional students are the focus of this study. These are defined as students with different qualifications or life experience in place of normally expected formal qualifications required for UK undergraduate study. These students may be mature (over 21 years old), or international students may be unable to study to an appropriate level within their local education system.

Learning the language of science is similar to learning a second language (Lemke 1990; Wellington and Osborne 2001). Vygotsky (1962), for example, drew comparisons between learning scientific concepts from spontaneous concepts to learning a second language and interaction with native language. This suggests that second language learning theories may provide useful insights into language acquisition in science. This study operates from the perspective that all chemistry students are non-native speakers of chemistry. Student chemical language usage is explored by linking two different conceptual frameworks, one each from second language and science education research. From second language research, we draw on interlanguage (Selinker 1972) as a conceptual framework for transitional language development. We apply this to the science education framework provided by Johnstone's triplet (Johnstone 1991) with particular focus on student acquisition of sub-microscopic language and transitioning from macroscopic and sub-microscopic levels.

### Interlanguage—Progression from Native to Target Language

The development of interlanguage as a psycholinguistic theory in second language research (Corder 1967; Selinker 1972) represented a major shift away from viewing learner language as a defective form of target language towards a developing system with its own structure. Interlanguage is a theoretical framework applied to understand psycholinguistic structures and processes underlying attempted meaningful performance in a second language (Selinker 1972). Meaningful performance refers to situations in which a learner attempts to express meanings in a language they are in the process of learning (the target language). Error analysis of student utterances indicated that the errors did not originate from the target language or learners' first language, indicating that they must be internally realised by the learner (Ellis 1985). The term *interlanguage* was proposed by Selinker (1972) to describe this idiosyncratic learner language and is identified 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 et al. 2013, p. 36). Interlanguage may be regarded as lying on a continuum between learners' native and target language. At any point along the continuum, the learner's language is systematic and differences may be explained by learning experiences (Freeman and Long 1991). Selinker (1972) stated three main characteristics of interlanguage. The first is permeability. This means that rules constituting learners' knowledge at any stage are not fixed but open to amendment. This is essential if interlanguage is to progress towards target language. Second, interlanguage is dynamic or constantly changing as the learner progresses towards target language, making revisions. Lastly, interlanguage is systematic. The learner does not select accidentally from their store of interlanguage rules but in predictable ways. Learners produce systematic utterances

whether or not these are native like. However, learner language systems are frequently unstable and characterised by high degrees of variability (VanPatten and Williams 2007), with utterances varying from moment to moment. This lack of stability and therefore capacity to identify systematicity is a critique of interlanguage (Al-Khresheh 2015).

Data supporting evidence for interlanguage are obtained from utterances produced when a learner attempts to say sentences in the target language. Examples of interlanguage include overgeneralisation of target language rules to situations where they do not apply (Selinker 1972). An example is the collocation *drive a bicycle* in the sentence “I decided to start on the *bicycle* as slowly as I could as it was not possible to *drive* fast”. Interlanguage has been established in target languages during formation of negative sentences with learners working through developmental stages (Mitchell et al. 2013). Interlanguage is a dynamic transitional process that may result in incomplete attainment of the target language. The learner remains at this interlanguage stage and never masters the target the language, a process referred to as *fossilisation* (Selinker 1972).

Within science education research, the existence of transitionary discourse has been investigated. Bakhtin (1981) termed transitionary discourses as hybridisation, and several studies describe the occurrence of hybrid discourse and hybrid discursive spaces (Ash 2008; Baquedano-López et al. 2005; Gutiérrez et al. 1999; Leander 2002; Miano 2004). Blown and Bryce (2017) demonstrated how children fluctuated between everyday and scientific language in both directions when providing explanations of daytime and night time. Ash (2008) argues that fluctuation between scientific terms and everyday terms demonstrates a hybrid discourse leading to shared understanding. Lemke (1989) recognised a tension between scientific and colloquial or everyday ways of speaking. He 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 become bilingual in colloquial and scientific English. 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, students develop a hybrid or interlanguage. Lemke (1990) states that students should engage in regular translation practice from colloquial to scientific English and vice versa. Studies identify that students who use colloquial language may find accessing foreign scientific ways of speaking very difficult (Ballenger 1992, 1997; Barton 2003; Delpit 1988; Gee 2005; Heath 1983). This may result in these students not progressing to higher levels of study.

Interlanguage occurrence in 17-year-old Swedish students’ discussion of evolution was investigated by Olander and Ingerman (2011). Three prominent conceptual notions in students’ discussion were identified. These were *randomness*, *need* and *development*. Students alternated between colloquial and scientific language but developed school science explanations as discussions progressed. Colloquial language was not considered problematic, but discursive negotiation enabled students to move towards a scientific explanation for evolution. International students were found to misinterpret words unexpectedly due to everyday usages in their native language. Therefore, these linguistic challenges have the potential to prevent these students from achieving their potential in science.

Selinker (1972) highlighted backsliding, that is, reappearance of linguistic phenomena previously thought to have been eradicated, as characteristic of interlanguage. This phenomenon was noticeable when learners are presented with challenging subject matter or in a state of anxiety. Rincke (2011) refers to backsliding in a study of 47 secondary school students’ conceptual understanding of mechanics. He investigated occurrence of language learning

processes such as interlanguage when students were developing scientific explanations of scenarios involving force. A series of mechanics lessons were designed that differentiated everyday and scientific usage; scientific usage of *force* denoting at least two partners involved in an interaction was explained. Mixing everyday and scientific usage of force was avoided. He 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 revealed students' experienced difficulty adopting scientific use of key terms, despite their teacher's exemplification and explicit guidance. Early on in the teaching sequence, students demonstrated a scientific understanding of force but in complex scenarios, and later in the teaching sequence, students reverted to everyday language. Rincke (2011) interpreted this as evidence of backsliding within a scientific interlanguage. Consequently, even when a teacher is under the impression that students have grasped relevant language, this may not be secure and requires further reinforcement.

Use of formulaic phrases is a further characteristic of second language learning (Rincke 2011). Language learners articulate phrases that are not formed creatively but recalled as a whole. This enables learners to express complexity that goes beyond knowledge of grammatical rules. Language learners are recommended to memorise short phrases of words that belong together rather than individual words. Use of formulaic phrases in science can result in rote learning and recital of key phrases with a limited understanding of concepts. The longitudinal aspect of Rincke's study establishes the existence of interlanguage in science as defined by Selinker (1972) by investigating language usage over time. The results presented herein provide insight into individual student scientific language usage over several years.

### Johnstone's Triplet

To participate in scientific discourse, chemistry students must operate between macroscopic, sub-microscopic and symbolic levels (Johnstone 1991). Referred to as Johnstone's triplet or the chemical knowledge triplet, Talanquer (2011) suggests this idea has become one of the most powerful ideas in chemical education.

Johnstone (1991) identified three levels: macroscopic, that is, what can be seen, touched and smelt; sub-microscopic, that is atoms, molecules, ions and structures; and symbolic meaning, representations of formulae, equations, mathematical expressions and graphs. Inspired by a geologist's diagram describing mineral composition, Johnstone arranged these levels at the apexes of an equilateral triangle to indicate equal, complementary significance. Teaching occurs within the triangle, under the assumption that all levels are equally well understood. During chemistry learning, novice students must move between these three levels, often without notice or explanation. This introduces significant complexity for novice chemists. Each level has its own characteristic language, and a successful learner develops competence in and confidently inter-relates these three aspects. To achieve this, learners must develop chemical linguistic confidence. Taber (2013) argued that conceptual demand is high at the macroscopic apex as students deal with abstract notions relating to substances with unfamiliar names and classifications, for example, *alkali metals*, *acids* and *reducing agents*. He highlighted the role of specialised language in chemistry and how macroscopic concepts, such as *solution*, *element* and *reversible reaction*, or sub-microscopic ones, including *electron*, *orbital* and *hydrated copper ion*, need to be represented for a novice to use when thinking about concepts and sharing understanding. Sub-microscopic explanations make considerable demands on novice learners as they are required to accept the existence of minute theoretical

entities, understand their nature and then use them in developing explanations. This study investigates the ability of six non-traditional (novice chemistry) students acquiring and using appropriate macroscopic and sub-microscopic language to explain scientific scenarios.

## Aim and Research Questions

The aim of the study was to investigate student usage of chemical language to explain three chemical scenarios over time. Responses were analysed for correct use of scientific language with a particular focus on occurrence of interlanguage when transitioning between macroscopic and sub-microscopic levels. The longitudinal aspect provided opportunities to investigate systematic changes and developments in language use over time.

The study was guided by these research questions:

- 1) In what ways do students demonstrate chemical interlanguage when explaining scientific scenarios transitioning between macroscopic and sub-microscopic levels?
- 2) To what extent are students able to use sub-microscopic language appropriately?

The study is conducted from a social constructivist perspective (Vygotsky 1962) in which language is learnt through interaction. Vygotsky's approach offers a useful standpoint from which to view language and conceptual development. Vygotsky (1962) differentiated between spontaneous and scientific concepts. Spontaneous concepts emerge from a child's reflection on everyday experience. Scientific (academic) concepts originate in the classroom activity and develop logically defined concepts. Vygotsky was interested in facilitating learning to enable a child to progress from spontaneous to scientific concepts. He argued scientific concepts do not come to learners ready-made but work their way down whilst spontaneous concepts work their way up, meeting the scientific concept and allowing the learner to accept its logic (Fosnot and Perry 1996). Vygotsky referred to the interface where a child's spontaneous concepts meet the teacher's scientific concepts as the zone of proximal development (ZPD). This is defined as the distance between the actual developmental level determined by independent problem-solving (zone of actual development (ZAD)) and the level of potential development as determined through collaborative problem-solving with more capable peers. Vygotsky's work represents a significant shift in moving education from knowledge transmission towards knowledge construction. Thus, the teacher does not dispense knowledge but supports or scaffolds students progressing from their current understanding and language competence (ZAD) into their ZPDs; as new levels are attained, scaffolding is altered accordingly.

## Study Context and Sample

The study is situated within the context of a Foundation Centre at a university in the UK. The Foundation Centre is an initiative that aims to extend the range of students studying undergraduate (bachelor's) programmes, referred to as widening participation. The Centre thus recruits non-traditional students, who do not possess qualifications accepted for direct entry into year 1 (or *level 1*) of a bachelor's degree. These are typically mature students (over 21 years old) who may have completed formal education at the age of 16 or 18 then held

various types of employment and/or had caring or other responsibilities. Some Foundation students are international coming to the UK for a pre-bachelor's degree study year.

The Centre delivers a 1-year intensive, academic Foundation programme. Approximately 50 science students study chemistry in the first term (October–December) only. These students progress to biology, biomedical science, chemistry, computer science, engineering, medicine, pharmacy and physics. Those progressing to biology, biomedical science, chemistry, medicine and pharmacy degree courses study chemistry from October to June. A summary of the course schedule and content is presented in Appendix 1. The course included a range of language-focussed activities as described in Rees et al. (2018a).

Six students aged 18–36 (three males and three females), who were progressing to chemistry, biological science and medicine, were invited to participate. The students comprised a selective sample to reflect a range of non-traditional backgrounds. Students were ascribed pseudonyms which are used throughout, and details are summarised in Table 1. Two students, Ferne and Linda, were supporting their families whilst studying. Neil and Kirsty were returning to study after several years in full-time employment. Evan and Adam were international students who had been unable to study to the level required for direct undergraduate entry.

## Methodology

Data were collected via semi-structured interviews using scientific scenarios. The scenarios are stated in Table 2 and described in full below.

Students were interviewed two or three times during academic year 1, then annual interviews up to year 2 (Ferne, Linda, Evan and Adam), year 3 (Neil) or year 4 (Kirsty). The academic year runs from October to June. Interviews were recorded by Dictaphone for transcription. Interviews took place in teaching rooms with only the interviewer and interviewee present for 1 h each. Questions were asked in two stages: first, a general discussion took place about students' experience of teaching and learning strategies and wider issues affecting their studies such as housing or finance, and the second stage focused on the scientific scenarios. The interviewer was aware that by the act of asking a question, a linguistic context is introduced which influences students' response.

## Scientific Scenarios

The scenarios prompted students to *think aloud* about a scientific event (Gunckel et al. 2012). The scenarios are described in Table 2, showing the connection to content taught in the Foundation programme and the chemical language expected. The scenarios were chosen

**Table 1** Interview student backgrounds (mature = over 21 years old)

| Pseudonym | Gender | Background    | Undergraduate degree route |
|-----------|--------|---------------|----------------------------|
| Ferne     | F      | Mature        | Biological science         |
| Linda     | F      | Mature        | Biological science         |
| Kirsty    | F      | Mature        | Biological science         |
| Evan      | M      | International | Chemistry                  |
| Adam      | M      | International | Chemistry                  |
| Neil      | M      | Mature        | Medicine                   |

**Table 2** Interview scientific scenarios and relevant terminology

| Scenario  | Year 1 course week | Relevant terminology  |  |
|---|--------------------|---|--|
|   |                    | Sub-microscopic   | Macroscopic  |
| Amount of substance: 10 g of lead contains fewer atoms than 10 g of sodium—can you explain why?                       | 2                  | Relative atomic mass, $A_r$ , protons, neutrons, electrons, atom  | Mass, moles, molar mass, Avogadro's constant, carbon 12, substance, elements   |
| States of matter: I blow on a cup of coffee and my glasses steam up—can you explain why?                              | 4                  | Particles, molecules, kinetic energy, vibration, electronegativity, covalent bond, polarity, dipole, hydrogen bonding, intermolecular forces, partial charge, delta positive/negative, electrostatic attraction | Solid, liquid, gas, evaporation, condense, water, hydrogen, oxygen, heat, cool |
| Benzene: benzene requires a catalyst to react with bromine whereas cyclohexene and phenol do not—can you explain why? | 13                 | Electrophile, delocalised electrons, electron cloud, electron density, activate, sigma bond, pi bond, double bond, lone pair, polarisable, dipole, induce, delta positive                                       | Solution, orange, colourless   |

because of their relevance to the course content and the range of sub-microscopic and macroscopic language required to explain them. Further detail of the course content is provided in Table 5 in Appendix 2.

## Analysis

Transcription involved content analysis for language use and communication. Detailed transcription was undertaken with intonation and pauses recorded. The first instances of correct use of chemical language (CCL) and incorrect use of chemical language (ICL) were recorded and totalled for each scenario for each individual student.

Content analysis was used to quantify responses in terms of predetermined categories of chemical language usage in a systematic and replicable manner (Bryman 2016). This was informed by error analysis from second language learning (Corder 1967). That is to say, identifying language errors which are systematic reveals underlying knowledge of the language or transitional competence. The data was interrogated using an organising framework (Barbour 2013) that identified overall correct and incorrect chemical language usage. 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.

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. If a word was used



incorrectly and correctly within one interview, it would score 1 in both categories. Themes were then identified in the data corresponding to Johnstone's triplet (Johnstone 1991) and chemical interlanguage (Selinker 1972).

## Ethics

The study was given ethical consent by the University's Foundation Centre ethics committee. Students were fully informed about the study and gave permission for interview data to be recorded and analysed. They were able to withdraw from the study at any time. The ethical procedures applied are in line with those recommended by BERA (British Educational Research Association [BERA] 2018) for educational research.

## Results

### Chemical Interlanguage

This section discusses examples of chemical interlanguage in students' explanations. We identified potential chemical interlanguage within five different themes: transitioning from vague to defined use, everyday and scientific language, interchanging, omissions and formulaic phrases.

#### Transitioning from Vague to Defined Use

In the states of matter scenario, students demonstrated increasing use of sub-microscopic language during year 1. Progression from vague to defined usage was evident. Linda, for example, tried to explain polarity using electronegativity: "In the molecule, [yes] 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'".

She is attempting to use newly acquired vocabulary. However, her meaning is vague and there is no qualification of electronegativity by stating a *difference* in electronegativity between oxygen and hydrogen.

In contrast, 3 months later, Linda states: "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".

Her language usage has progressed by stating one atom is more electronegative. Hence, there is a chemical interlanguage stage of progressing from vague use of terms with no qualification to use of the term *with qualification*.

Explanations of *dipole* by the students illustrate similar progression from use of no qualification or comparator to use of a comparator and, finally, to scientific qualification (Table 3). Four students provided responses characterised as only referring to *positive* and *negative* ends of a molecule. There was no distinction made about the strength of charge compared to a positive or negative ion. For example, Kirsty 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. Neil, for example, explained "there is a dipole in the molecule, [pause] you've got the oxygen and the hydrogen and the oxygen is 'a bit' negative and the hydrogen is 'a bit' positive". This level of response suggests that the



**Table 3** Chemical interlanguage progression describing polar molecules

|         | Language level           |                            |                             |                                | Scientific language                       |
|---------|--------------------------|----------------------------|-----------------------------|--------------------------------|---|
|         | No comparative qualifier | Comparative qualifier      |                             |                                |   |
| Example | Positive/<br>negative    | More positive/<br>negative | A bit positive/<br>negative | Slightly positive/<br>negative | Partial charges (delta positive/negative) |

student recognises there is a distinction between the strength of the charge in this context compared to ions.

Expert responses refer to *partial charges* or *delta negative/positive*. Two students demonstrated use of delta negative in year 2. Evan, for example, stated: “this side will have more [pause] electron density and cause and induce that become ‘delta negative’”.

There was no clear progression over time from no comparator to scientific language usage. Linda interchanged between using qualifiers (“it is ‘a bit’ positive and ‘a bit’ negative so it reacts”) and no qualifiers (“because one bromine is positive and one is negative”) within the same interview.

Student use of appropriate comparators such as *larger*, *smaller*, *greater* and *fewer* is evidence of interlanguage. Evan showed examples of self-correcting comparator choices, but not necessarily for an expert-level alternative. For example, Evan stated: “because the relative atom mass for the sodium is ‘hi’, [pause] is bigger than that of the lead”. The utterance *hi* indicated he was about to say *higher* but replaces this with the less scientific *bigger*. Kirsty used the comparator *stronger* rather than *higher* when talking about electronegativity. She stated: “the electronegativity for oxygen is stronger than the hydrogen electronegativity”. In the state of matter scenario, Linda 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*.

### Combining Everyday and Scientific Language

Early interviews provided examples of students using everyday language to explain macroscopic phenomena at the sub-microscopic level. For example, in relation to states of matter, Kirsty stated: “energy gets taken away and it gets dropped down to a liquid”. *Energy gets taken away* refers to transfer of energy from gaseous water molecules to glass. Kirsty used chemical interlanguage to convey understanding of energy transfer but does not use the expert vocabulary *transfer*. *Dropped down to a liquid* indicates chemical interlanguage to convey understanding of change in state. *Dropped down* suggests interpretation of state change from gas to liquid as a downward process perhaps in terms of energy change. Kirsty described molecules in a liquid “as layers over each other transient moving”, and Linda referred to molecules in a liquid as “a kind of varying motion driven state”. The precise meaning of these unique utterances is unclear, but they convey a sense of molecules passing over each other.

When responding to the benzene scenario, Linda stated: “the OH group itself is sort of slightly destabilising the molecule”. Linda thought electrons from the oxygen atom interact with the benzene ring, decreasing stability and increasing reactivity of the molecule. The use of *destabilising* is an example of a scientific term used that is not expert but conveys some appropriate understanding.

Other examples were less useful for conveying appropriate meaning. For example, when discussing arrangement of molecules in a liquid, Neil described intermolecular forces as "... staples it together to form a liquid". The term *staples* suggests a rigid or fixed nature to interactions between water molecules. This contrasts with Linda's examples suggesting a fluid arrangement.

During teaching, everyday language of *pulling power* is used to explain electronegativity. This refers to the ability of one atom to attract an electron pair in a covalent bond more than the other. Hence, one atom has more pulling power than other atoms. This phrase was used by Linda and Ferne when discussing electronegativity. Linda used pulling power instead of *electronegativity* 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 chemical interlanguage: although the language is not expert (*molecule* is used instead of *atom* and the reference to *hydrogen exposed*), it conveys appropriate understanding. Ferne used pulling power in conjunction with *electronegative* 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 electronegativity.

In these examples, students oscillate between everyday and scientific language in a similar way to observations reported by Blown and Bryce (2017). Ferne's explanation is at a higher level, as it is used in conjunction with electronegative, whereas Linda does not refer to electronegativity. This illustrates chemical interlanguage with progression from the sole use of everyday language to a combination of everyday and scientific language and, finally, to the sole use of scientific language.

## Interchanging Terms

Explanations of the amount of substance scenario provided examples of consistently interchanging terms. Five students interchanged use of *relative molecular mass* and relative atomic mass. At the end of year 1, for example, Evan consistently used relative molecular mass rather than relative atomic mass. After a discussion about differences between atoms and molecules, Evan corrected his language and referred to relative atom (sic—atomic) mass. Ferne used relative molecular mass but corrected herself when questioned. Linda initially referred to *atomic mass* and checked herself as to whether it should be molecular before deciding that atomic mass was correct. She talked about *molecules of lead and sodium* and *molecular mass of lead*. Kirsty referred to relative molecular mass, did not correct it and referred to *molecules of carbon* and *hydrogen*. Adam used the phrase *molecule mass* but corrected to *atoms* when questioned. This incorrect and systematic use of molecule rather than atom may have limited impact on explaining the scenario at the sub-microscopic level. That is to say, correct understanding of the relationship between the different sizes of the atoms and how this affects the number of atoms in a given mass could still be conveyed by the incorrect use of molecule. However, interchanging atoms and molecules could indicate a lack of understanding of the difference between these two words and have a significant effect on the broader understanding of chemistry beyond this scenario. There are similarities with this example to overgeneralisation of target language rules described by Selinker (1972). In this instance, the students have learnt the word molecule and are overgeneralising its use into inappropriate contexts.

Interchanging of terms also occurred with similar sounding terms. For example, at the end of year 1, Ferne used sub-microscopic chemical language when discussing reactivity of phenol in the benzene scenario. She referred to *delocalised electrons*, *electron cloud*, *curly arrows* and *inducing dipoles*, but her explanation was disjointed. She incorrectly referred to electrons from

the oxygen atom *reacting* (sic—interacting) with delocalised electrons. In year 2, Ferne referred to ‘electron substitution’ and ‘electron addition’ rather than *electrophilic*, when naming mechanisms. In the same scenario, Linda referred to *dislocated electrons* rather than delocalised electrons.

Electronegativity or electronegative was confused with terms such as *negative* or *electron density*. Kirsty, 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”.

The key word ‘electronegative’ is incorrectly used. Negative would have been appropriate. The comment loses meaning, so Kirsty lost confidence in her response after this error and is unable to develop the explanation further.

At the end of year 3, Neil recalled *electrons* and *neutrons* but referred to *positrons* rather than *protons*. This error may be caused by positrons being an active word in a medical context. In these instances, incorrect use of terms leads to confused understanding.

### Omission of Terms

Chemical interlanguage is found in omission of atom or molecule when discussing size of atoms. 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...one mole of hydrogen is in one gram of hydrogen”.

Lack of reference to *hydrogen atoms* and ambiguous reference to *molecules* make meaning unclear. However, Kirsty understands that a certain mass of hydrogen equates to 1 mol. To progress to expert language, the correct use of atoms or *molecules* is required.

### Formulaic Phrases

There is evidence students adopted formulaic phrases. Ferne referred to “activate the ring” when explaining the reactivity of phenol, but her understanding of the phrase appeared unclear. In year 2, Linda used the phrase “thermodynamically favourable over thermodynamically unfavourable” when discussing the states of matter scenario but was unable to elaborate on the explanation. These examples suggest that students sometimes use formulaic phrases but may have a limited understanding of their meaning.

### Use of Sub-microscopic Language

This section analyses interview data for the development of usage of sub-microscopic language to explain the scientific scenarios.

#### States of Matter

Table 2 gives the expected sub-microscopic vocabulary for the states of matter scenario. Adam and Kirsty provided very limited explanations of the scenario, at the beginning of year 1, recording low CCL scores of 3 and 5, respectively. Everyday words they used at the macroscopic level were *liquid*, *energy* and *evaporating*. For example, Kirsty said: “once they become steam they start to move about, spread out because they are no longer liquid so they just start to move out”. They were unable and/or unwilling to use sub-microscopic language.

Adam showed knowledge of changes in kinetic energy but struggled to recall the word *kinetic*. Adam's language skills restricted his ability to provide an explanation at the level of his internal understanding and affected his ability to participate in classroom discussions.

Kirsty demonstrated knowledge of particulate movement, but when asked to explain the effect of temperature on water particles, she responded: "I think that's about as much as I am going to be able to answer." She lacked knowledge to develop her response further, indicating the limit of her ZAD (Vygotsky 1962).

Towards the end of year 1, Adam and Kirsty used CCL increasingly frequently, scoring 10 and 13, respectively. Adam used some sub-microscopic language and referred to molecules *moving faster*. His vocabulary remained limited and was unable to recall the word kinetic. He looked up *hydrogen bonds* on his smartphone and misunderstood the meaning of *hydrogen bond* as a bond between two hydrogen atoms. He did not understand dipole and made no reference to electronegativity. Therefore, by the end of the year, Adam had not acquired vocabulary to provide a sub-microscopic explanation.

At the end of year 1, Kirsty used relevant sub-microscopic language, referring to *hydrogen bonding* and *van der Waals' bonding*. She was initially unsure which type of bonding was correct but decided on hydrogen bonding. She tried to provide an explanation of hydrogen bonding but became confused with incorrect use of electronegative. This resulted in her losing confidence in her explanation and giving up. Kirsty demonstrated increasing confidence during year 1 in developing her explanations. Difficulties in using relevant scientific words such as electronegativity created challenges for her to engage successfully within a social constructivist environment.

Four students (Ferne, Linda, Neil and Evan) used some sub-microscopic language and had CCL scores of 7, 8 and 9, respectively, at the start of the year. These scores are higher than those of Adam and Kirsty. These students used everyday macroscopic words, such as liquid and gas, and referred to molecules, *particles*, *bond* and *vibrates*. Ferne, for example, talked about "liquid water which is molecules I think closely packed and they slide around". However, none of these students demonstrated knowledge of intermolecular forces or referred to dipole, hydrogen bonding or electronegativity.

At the end of the year, these students increased their CCL scores to 15 (Ferne), 13 (Linda), 17 (Evan) and 16 (Neil). The students used sub-microscopic vocabulary such as hydrogen bonding, dipole, negative, *intermolecular forces* and *lone pair of electrons*. Only Linda used the word electronegativity correctly by this stage.

Table 4 shows that few sub-microscopic words that were used initially, but usage increased by the end of year 1.

Progressing into year 2, Ferne, Linda, Kirsty and Evan used sub-microscopic language appropriately. Ferne, for example, provided a response at the sub-microscopic level and used words such as electronegative, electron cloud and hydrogen bonding. Linda described polarity in the water molecule and used hydrogen bonds, *nonpolar* and electronegativity appropriately. However, in year 4, Kirsty was unable to recall relevant sub-microscopic vocabulary or provide coherent explanations.

## Amount of Substance

This section analyses responses to the amount of substance scenario during year 1. Initially, Evan used sub-microscopic chemical language to explain the scenario (CCL score = 10). He referred to relative atom (sic—atomic) mass,  $A_r$ , *atomic number*, protons, electrons and

**Table 4** Year 1 usage of five sub-microscopic words from the states of matter scenario

| Student year 1 interview | Ferne |     |     | Linda |     |     | Evan |     | Neil |     | Adam |     | Kirsty |     |
|--------------------------|-------|-----|-----|-------|-----|-----|------|-----|------|-----|------|-----|--------|-----|
|                          | 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 (atoms)           |       | 1   | 1   | 1     | 1   |     |      |     | 1    |     | 1    |     | 1      | 1   |

\*The number 1 indicates correct usage

neutrons. He used chemical words appropriately and demonstrated correct understanding even though language use was sometimes not fluent. For example, he states “...we use mass divided by Ar atom, relative atom mass and we can calculate how much mole of it”. At the end of year 1, Evan consistently used relative molecular mass rather than relative atomic mass. After a discussion about differences between atoms and molecules, Evan corrected his language and referred to relative atom (sic—atomic) mass. He did not demonstrate significant progress in his sub-microscopic language.

Ferne, Linda, Adam, Neil and Kirsty used limited chemical language to explain the scenario (CCL scores from 1 to 7) initially. Their vocabulary comprised atoms and particles and macroscopic words (mass, *substance* and *grams*). Ferne referred to atoms being bigger and *containing more protons* but was unable to use relative atomic mass. Neil referred to atoms being larger but was unable to explain this in detail. Linda recognised lead was a larger atom and had a *higher atomic mass*. She referred to *weight* of substance rather than mass.

During year 1, Ferne, Linda and Kirsty showed improved usage of chemical language such as *moles* and molar mass. Adam and Neil showed limited progress. Ferne, Linda, Kirsty and Adam referred to relative molecular mass. Ferne used relative molecular mass but corrected herself when questioned. Linda initially referred to atomic mass and checked herself as to whether it should be molecular before deciding that atomic mass was correct. She talked about molecules of lead and sodium and molecular mass of lead. Kirsty referred to relative molecular mass, did not correct it and referred to molecules of carbon and hydrogen. For example, she states: “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 of mole of something else”. Despite the error in the sentence (six grams of carbon is one mole) and the imprecise language use, she is conveying correct understanding of the concept of amount of substance. Adam used the phrase molecule mass but corrected to atoms when questioned. This incorrect and systematic use of molecule rather than atom is an example of chemical interlanguage.

Adam began with a CCL score of 1, increasing to 3 by the end of year 1. He used the word electron appropriately but did not use any further chemical language. 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. Ferne extended her chemical language usage with moles and molar mass although incorrectly stated that the molar mass of lead was less than sodium. She recalled *Avogadro's constant*. Linda continued to demonstrate confusion as to whether weight or mass was the

correct word. Therefore, although their use of sub-microscopic vocabulary had developed, they had difficulty providing coherent explanations.

In year 2, Ferne applied relevant sub-microscopic vocabulary such as moles and atomic mass but Linda, Kirsty, Neil and Adam struggled to provide a coherent explanation. In years 3 and 4, students struggled to recall relevant vocabulary or construct a meaningful explanation.

## Benzene

This section analyses responses of two interview students to the benzene scenario. In her initial explanation, Ferne referred to delocalised electrons and *electron clouds* appropriately and attempted to use *sigma* and *pi bonds*, demonstrating partial understanding. She referred to *induce a dipole* but confused this with electronegativity (a possible confusion with electron density). Incorrect use of electronegativity correlates with the states of matter scenario. She made a third use of *delocalised* in the phrase *delocalised bonds*. She demonstrated willingness to explain the scenario and to use appropriate terminology but could not explain the reactivity of phenol.

Linda's initial explanation was limited. She showed some awareness of the structure of benzene and mentioned pi bonds. She stated: "the electrons are spread out all around the ring". She demonstrated understanding without using scientific vocabulary such as delocalised. She was aware that cyclohexene is an alkene and, therefore, contains a carbon=carbon double bond. She mentioned *polarity* and had an idea of positive and negative charges but was unable to expand. She was aware of the structural difference and the presence of an -OH group in phenol but was unable to explain how this affects the molecule.

At the end of year 1, Ferne used a range of sub-microscopic chemical language when discussing reactivity of phenol. She referred to delocalised electrons, electron cloud, curly arrows and inducing dipoles. Her explanation was disjointed, and she incorrectly referred to electrons from the oxygen atom reacting (sic—interacting) with delocalised electrons. Ferne demonstrated good use of delta negative (rather than saying negative). Ferne had successfully incorporated some sub-microscopic vocabulary but could not produce a coherent explanation by the end.

Linda applied chemical language to explain the scenario correctly (CCL = 20) and incorrectly (ICL = 4) at the end of year 1. She explained the structure of benzene and applied terms such as delocalised and sigma appropriately. She was less confident about using electrophilic and incorrectly applied polarity. Linda inappropriately used electronegativity. Linda had successfully acquired some sub-microscopic vocabulary but had difficulties providing an explanation at the end of year 1.

Ferne and Linda responded to the benzene scenario at the end of year 2. Ferne correctly recalled sigma and pi bonds. She referred to electron cloud but recalled mechanism names such as *electron substitution* and *electron addition* rather than electrophilic. Linda referred to dislocated electrons rather than delocalised electrons and incorrectly used electronegativity. Both students struggled to explain the scenario.

## Discussion

In relation to research question 1, data indicate the occurrence of potential chemical interlanguage classified within five themes, namely vague to defined use, everyday and scientific language, interchanging, omissions and formulaic phrases. Identification of



transitional chemical language themes corresponds to stages of non-traditional student progression along a continuum from native (everyday) to target (scientific) language. This evidence suggests how student acquisition of chemical language is (partly) analogous to second language acquisition. Limitations of this include interlanguage having its own grammar or systematic rules that are distinct from native and target languages. The grammar of chemistry corresponds to English, with unique characteristics applied when naming organic compounds or using chemical formulae. Themes identified here do not allude to a unique grammar. The analogy of chemical interlanguage proposed here is restricted primarily to the lexicon. Selinker (1972) identified characteristics of interlanguage as being permeable and dynamic. The rules constituting learners' knowledge at any stage are open to amendment. These data show evidence of permeability and a dynamic process. For example, the theme of transitioning from vague to defined use identifies interim stages in relation to electronegativity and *polar molecules*. There was evidence of students' language use developing over time and using different variants of target language form. In relation to the theme of combining everyday and scientific language, the situation was dynamic with different language combinations identified. Interlanguage is systematic, with identifiable rules applied by the learner methodically. In second language learning, this commonly applies to grammatical rules. However, each theme identified here could represent students' rules of chemical interlanguage. For example, combining everyday and scientific language provides evidence of systematicity, as students applied this strategy at different times in potentially methodical ways. This phenomenon has been reported elsewhere (Blown and Bryce 2017). Interchanging terms and use of similar words but with different meanings was widespread. This is consistent with Vladušić et al. (2016). How methodical these errors are is unclear. Therefore, we postulate these are emergent chemical interlanguage themes that require further investigation regarding the extent to which they represent identifiable stages in chemical language acquisition. The existence of chemical interlanguage has implications for students developing correct conceptual understanding. Combining everyday and scientific language is a valuable strategy to develop understanding of scientific language. This only works if the everyday language conveys appropriate meaning. When engaged in subject-specific discourse, chemical interlanguage used by learners will impact understanding conveyed and interpreted.

In relation to research question 2, data indicate acquisition and use of sub-microscopic language was highly variable amongst these non-traditional students in year 1 regardless of background or progression route. For example, only Linda developed appropriate use of electronegativity in the states of matter scenario. This word may be particularly challenging because it is highly unlikely to have been a word that the students have come across before and its understanding and use is within the sub-microscopic level. The word also gives little indication of its chemical meaning (the ability of an atom to attract a bonded pair of electrons within a covalent bond) and was also confused with similar terms such as electron density. The cumulative effect of these different factors increases the linguistic demand upon the student (Rees et al. 2018b). Therefore, despite the language-focussed pedagogy in year 1, some of the students were unable to develop competent use of this language. Consequently, it is more difficult for the students to progress within their ZPD because of their limited chemical language competence. The challenges for students operating at the sub-microscopic level are well documented as they are required to understand the nature of these minute theoretical entities and then use them in their explanations (Taber 2013). The results presented here highlight the difficulties for novice chemistry students to successfully acquire sub-microscopic language and then use it to develop coherent explanations and conceptual understanding.



Variability in sub-microscopic language use was also apparent during year 2. Ferne, Linda, Kirsty and Evan used appropriate sub-microscopic language in the states of matter scenario. These students had continued to develop their use of this vocabulary within the first year of their undergraduate degree. Adam and Neil, however, did not and may be fossilised (Selinker 1972) at an interlanguage stage. Sub-microscopic language use by Linda and Ferne in the benzene scenario deteriorated in year 2 compared to year 1, indicating relevant language had not been prominent during the first year of their undergraduate studies. This was also the case for the other scenarios for Neil in year 3 and Kirsty in year 4, indicating that without regular language practice, their ability to use chemical language to explain the scenarios had deteriorated. In these instances, the students may be backsliding (Selinker 1972) within their interlanguage towards previous novice language use, highlighting the importance of regular reinforcement (Rincke 2011).

We argue, therefore, for greater emphasis on language acquisition and awareness of how this relates to learning progressions of chemical concepts. As with second language learning, this shifts viewing learner language as a defective form of the target language to a developing system lying on a continuum towards mastery of chemical language. This informs pedagogy, and the contributed language-focused teaching strategies can potentially make to develop student language abilities that result in improved scientific reasoning (Rees et al. 2018a, b).

## Limitations

This exploratory study was restricted to a limited number of six non-traditional students with varying backgrounds within one educational context. They provided explanations for a limited number of scenarios. Data provide useful insights into language development in this context. Further research is required to establish generalisability of patterns of language acquisition and the extent and significance of chemical interlanguage described.

## Appendix 1. Semi-structured interview protocol

- 1) Student thanked for attending interview and reminded of the basis of the research and their voluntary participation.
- 2) Question: How have you found your experience from a teaching and learning perspective this term?
- 3) Question: Are there any particularly useful strategies that you have experienced or developed?
- 4) Question: Are there any aspects of your wider experience that is affecting your studies?
- 5) Scenario: Amount of substance: 10 g of lead contains fewer atoms than 10 g of sodium—can you explain why?
- 6) Scenario: States of matter: I blow on a cup of coffee and my glasses steam up—can you explain why?
- 7) Scenario: Benzene: benzene requires a catalyst to react with bromine whereas cyclohexene and phenol do not—can you explain why? (Ferne and Linda only).
- 8) Question: Do you have any other comments you would like to make?
- 9) Student thanked for attending and interview concluded.

## Appendix 2

**Table 5** Summary of year 1 teaching schedule and content

| Week        | Topic  | Summary content   |
|-------------|--|---|
| 1 October   | Atomic structure<br>Elements and compounds                             | Development of ideas of atomic structure<br>Explanation of the Bohr model<br>Determining the number of protons, electrons and neutrons<br>Chemical reactions to illustrate chemical change and explore understanding of elements and compounds and chemical reactions     |
| 2           | Relative atomic mass (RAM)<br>Amount of substance<br>Empirical formula | Develop understanding of relative atomic/molecular mass<br>Calculate RAM from percentage abundance data<br>Calculate the amount of substance in moles from mass<br>Undertake practical experiments to determine the empirical formula of magnesium oxide and copper oxide |
| 3           | Electron configurations<br>Bonding and structure                       | Electron configurations of the first 20 elements determined using $1s^2, 2s^2$ , etc.<br>Introduced to ionic and covalent bonding, giant lattices and molecular structures<br>Practical experiments investigate the physical properties of ionic and covalent compounds   |
| 4           | States of matter<br>intermolecular forces<br>Shapes of molecules       | Kinetic theory discussed as a basis for changes in state<br>Occurrence of different intermolecular forces discussed<br>Shapes of molecules explored, e.g. tetrahedral, octahedral   |
| 5           | The periodic table   | Historical development of the periodic table and trends in main groups discussed<br>Practical experiments explore trends in group 1 and group 7   |
| 6           | Acids and bases<br>Volumetric analysis                                 | Students introduced to the pH scale and Brønsted-Lowry acid base theory<br>Reactions of acids and bases explored  |
| 7           | Mid-term review<br>Concentration calculations<br>Equilibrium           | Content covered reviewed with a formative test<br>Titration experiments undertaken and amount of substance from concentration covered<br>Principles of physical and chemical dynamic equilibria illustrated with practical experiments (iodine and cobalt chloride)       |
| 8           | Oxidation states<br>Rate of reaction                                   | Determining oxidation states of elements in different compounds<br>Factors affecting rate of reaction<br>Practical assessment—an effect of temperature/concentration on the reaction of marble chips and acid   |
| 9           | Enthalpy changes   | Exothermic and endothermic reactions investigated and enthalpy changes calculated<br>Hess's law used to calculate enthalpy changes  |
| 10 December | Crude oil revision   | Introduction of crude oil and fractional distillation   |
| 11 January  | Organic chemistry<br>naming compounds                                  | Separation of crude oil revisited and naming of organic compounds explained   |

**Table 5** (continued)

| Week                      | Topic                                       | Summary content   |
|---------------------------|---|---|
| 12                        | Organic chemistry                           | Practical—aspirin hydrolysis  |
| 13                        | Alkanes, alkenes and aromatics              | Structure and halogenation of alkanes, alkenes and aromatics including mechanisms   |
| 14                        | The Victorian Pharmacy                      | Practical: reactions of alcohols and carbonyls<br>Identifying unknown (Victorian) chemicals                               |
| 15                        | Carboxylic acids, esters, fats and polymers | Structure and reactions to esters, triglycerides and polymers (addition/condensation)<br>Impact of diet and heart disease |
| 16                        | Electrochemistry                            | Practical: electrolysis of brine<br>Constructing electrochemical cells and calculating cell potentials and cell equations |
| 17                        | Born-Haber cycles                           | Born-Haber cycles to calculate lattice enthalpy<br>Trends in lattice enthalpy   |
| 18                        | Thermodynamics                              | Introduction to entropy and Gibbs free energy equation<br>Revision  |
| Easter vacation (5 weeks) |   |   |
| 19                        | Acids and bases                             | Calculating pH from hydrogen ion concentration<br>Determining $K_a$ and $pK_a$<br>Calculating pH of a weak acid           |
| 20 May                    | Equilibria                                  | Dynamic equilibrium and Le Châtelier's principle<br>Calculating $K_c$   |

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