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Metaphors of Climate Science in Three Genres: Research Articles, Educational Texts, and Secondary School Student Talk

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Experts are generally in agreement that anthropogenic climate change is happening and will increase in severity, but this view is not clearly reflected in more non-specialist texts. Research has shown that school students have a limited and sometimes faulty understanding of climate change. Metaphors are used by scientists in developing thought and communicating with non-scientists; they are also used by educators. This research investigates students' understandings of climate change by comparing metaphor use in three corpora, of research articles, student educational materials, and of transcribed interviews with school students aged 11–16 from the north of England. We find that some metaphors are shared by the three corpora; where this happens, the researchers' use tends to be highly conventionalized and technical, while educational materials extend and explore metaphors, and the students' use is still more creative, sometimes resulting in inaccurate descriptions of the science. Students also develop some of their own distinctive metaphors based on their immediate concrete experience, and possibly on visual educational materials; these metaphors convey highly simplified and often inaccurate understandings of climate science.

1. INTRODUCTION

Linguistic techniques can offer valuable insights into the communication and understanding of matters of public concern (Tang and Rundblad 2017). Climate change is one of the most urgent of such matters; to take just one recent news item, NASA reports that of the 12 months from October 2015 to September 2016, 11 set new monthly high temperature records (http://climate.nasa.gov/news/2503). There is widespread consensus among experts that warming is the result of human activity which has increased the amount of greenhouse gases, especially carbon dioxide, in the atmosphere. However, there is a discrepancy between this expert understanding and its communication to the general public. In a review of 928 research papers, Orekses (2004) found unanimous agreement among scientists concerning the human contribution to climate change, yet Boykoff (2011) reported a

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continuing tendency in the news media to suggest that scientists are undecided about the role of human activity, a view which is reflected in public perceptions (Farnsworth and Lichter 2012). In other words, the issue of potentially problematic incomplete or inaccurate understandings of (climate) science applies broadly to many different groups in society. Our focus in this article, however, is the understandings of school-age students in a particular country.

While still barely perceptible from an individual's perspective in England, where this study was carried out, climate change could have a major and negative impact on the current generation of young people and their descendants. We[1] have attempted to find out what a sample of school students aged 11–16 are told and understand about the topic, and to investigate the scientific accuracy of this, using various tools including linguistic metaphor analysis. This article reports a comparative analysis of metaphors used in academic texts, in pedagogical texts, and by young people during small-group interviews on the topic, and reflects on the implications of the findings.

2. METAPHOR AND SCIENCE

Cognitive metaphor theorists have shown that metaphor is central to thinking and language (Lakoff and Johnson 1999). It has been recognized for some time that metaphor plays a central role in the development of scientific knowledge. Gentner *et al.* (1997) report that the astronomer Johannes Kepler (1571–1630) consciously used analogy in his thinking; for instance, he hypothesized about the 'motive power', of the sun, a precursor of what we now understand as 'gravity', by using analogies with light. Boyd (1993) claims that parallels drawn between people and computers have been a major recent influence on the field of cognitive psychology, evidenced by linguistic metaphors such as 'encode', 'storage capacity', and information 'retrieval'. Brown (2003), himself a scientist, writes that '... much of what scientists do—how they conceive of productive experiments, what they observe, and their interpretations of observations—is governed by metaphorical reasoning' (p. 2). He cites the metaphorical use of 'chaperone', which was originally coined by researchers in 1978 to refer to a specific molecule that, when added to two solutions, seems to 'allow' a particular interaction between them to take place, and 'prevent' other interactions. This scientific meaning was metaphorically derived from the social meaning of 'chaperone', which in traditional societies referred to an older woman who accompanies a young unmarried woman in public in order to protect her and her reputation. Since 1978, the metaphorical, scientific concept of a 'chaperone' has been applied more widely, and is now used to describe a large class of molecules that support particular interactions and somehow prevent others.

This use of metaphor to develop thinking in science is termed 'theory constitutive', as opposed to its 'pedagogic' use to communicate science to non-experts (Boyd 1993). An example of a pedagogic use of metaphor is the well-known description of electricity as if it were flowing water, or,

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alternatively, as moving crowds of people (Gentner and Gentner 1983). The water analogy is common in school textbook descriptions, and is lexicalized through words such as 'current' and 'flow'. While Boyd (1993) presented theory-constitutive and pedagogic metaphors as different *types* of metaphors, subsequent studies have used the distinction to capture different *functions* of metaphors for scientific topics (Knudsen 2003; Semino 2008: 125–67). Indeed, in many cases, the same metaphorical models have developed scientific thought, been used for communication between scientists, and been used for teaching and communication with the general public. For example, Rutherford's 'solar system' model, once central to the development of ideas about the atom (Brown 2003), is also one of the best-known pedagogical models. It is still seen in school-level discussions of chemistry, though for scientists, it has long been replaced with metaphorical models that better reflect the current state of knowledge.

Different sets of writers/speakers and readers/listeners may use and understand the same metaphors in different ways, and with different levels of complexity. In some cases, there are different understandings of the same metaphors among experts and non-experts, which may also change over time (Nerlich *et al.* 2002; Nerlich *et al.* 2011). In the field of the genetic code and protein synthesis, metaphors were used for new ideas as the field developed, and became established linguistic terms (Knudsen 2003, 2005). Metaphorical terms such as 'translation' once helped to structure and support the field, and were influential in developing the line of scientific enquiry that has led to modern understandings of DNA. Now, however, they have no figurative quality to specialists; an established specialized metaphor is 'an almost literal expression with specific reference, similar to any other scientific concept' (Knudsen 2003: 1248). Knudsen argues that popularizations often 'open up', explore, and extend the metaphors of experts.

The extended use of expert scientific metaphors can lead to differences between, broadly speaking, expert and public understandings of particular topics and issues. It can, for instance, allow people to apparently accept new knowledge but fail to recognize the challenges that this knowledge presents to their existing world views. Blancke *et al.* (2014) traced the use of the 'natural selection' metaphor, originally used by Darwin to frame and drive his ideas about evolution. When the metaphor was used to communicate his ideas to the wider public, it was systematically interpreted as implying agency in the natural selection process, in keeping with the existing tendency to ascribe purpose and intentionality to evolution. Similar issues have also been found in the use of pedagogic science metaphors. Cameron (2002, 2003) analysed transcripts of school children discussing science metaphors used by their teachers and in textbooks. She found that, while some metaphors supported children's understandings, others led to alternative understandings that can be described as inaccurate, which were often unnoticed by teachers, for example the inference that the heart pumps air into the body, based on a metaphorical understanding of the heart as a (bicycle) pump. These various findings suggest that when

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different groups of people, such as experts and school students, use the same or related metaphors, it cannot be assumed that they intend or understand them in the same way.

3. TEACHING CLIMATE SCIENCE IN SCHOOLS

Since the 1980s, it has been agreed by bodies such as the UNESCO and the Royal Society that educating all students about science should have equal status with the more traditional goal of science education, that of training and selecting the scientists of the future (Fenshaw and Harlen 1999). This is part of the development of school students as future citizens so that they will be able to make informed decisions about the public interest in adulthood (Davies 2004; Morris 2014). Zeyer and Dillon (2014) see scientific literacy as essential to informed citizenship, and within scientific literacy, environmental and health literacy in particular. Shepardson *et al.* argue that understanding global warming and climate change 'is essential if future citizens are to assume responsibility for the management and policy-making decisions facing our planet' (Shepardson *et al.* 2009: 550), while Schreiner *et al.* write 'empowering students to deal responsibly with the climate issue should be an important goal of education' (Schreiner et al. 2008: 41–2).

The teaching and learning of climate science, and students' understandings of and attitudes towards it, have been investigated in a number of countries, including Germany (Niebert and Gropengiesser 2013, 2014), Italy (Tasquier *et al.* 2016), Australia (Dawson 2015), Singapore (Chang and Pascua 2015), and the USA (Shepardson *et al.* 2014; Busch 2016), and in multiple-site studies, such as Byrne *et al.*'s study in Sweden and England (Byrne *et al.* 2014). Results are largely pessimistic; a frequent finding is that school students do not understand the processes of climate change well, being poorly equipped to cope with problems for which there is not a simple solution (Arya and Maul 2016), and tending to see it as a linear rather than systemic phenomenon (Shepardson *et al.* 2011). Students also tend to confuse climate science with other environmental issues such as acid rain and the ozone layer depletion (Dawson 2015). Niebert and Gropengiesser (2014) reviewed 24 studies reporting young people's understandings of climate change, and found a large number of widespread misconceptions, the commonest being that there is a specific, fairly thin layer of greenhouse gases. The nature of sunshine is not well understood, being seen generally as an undifferentiated whole, rather than consisting of UV rays, light rays, and heat rays.

Most research into climate teaching and learning in school settings has used thematic analysis of scientific content, knowledge, and attitudes in teacher talk, teaching materials, and student discourse. Techniques have included classifying students' and/or teachers' utterances using groupings such as 'repertoires' (Byrne et al. 2014), 'conceptions of the climate system' (Shepardson *et al.* 2014), and 'frames' (Busch 2016), and testing students' knowledge using various techniques (Shepardson *et al.* 2009; Dawson 2015). While clearly all of

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these studies start from some form of language data, they do not analyse the language itself. There have been relatively few language- and/or metaphor-focused studies. A few notable exceptions are briefly discussed.

Román and Busch (2015) conducted a systemic-functional analysis of the language of US middle-school science textbooks, to examine how much certainty about climate change is attributed to scientists, and how agency for climate change is ascribed. Findings included that the extensive use of modal verbs in their corpus suggested uncertainty about climate change. This was reinforced where 'scientists' were mentioned as actors. The verbs used in collocation with 'scientists' suggest doubt rather than evidence-based certainty: 'Scientists were often said to think or believe but rarely were scientists said to be inferring from evidence or data' (Román and Busch 2015: 17). To examine human agency, the researchers examined pronoun use, whether and how actors were referred to, and whether there was mention of behaviour that could mitigate climate change. As is not uncommon in scientific texts, the subject of the verb was often an abstract noun denoting a process. They conclude from their detailed linguistic analysis that the texts they examined 'more closely match the public discourse of doubt about climate change than the scientific discourse' (Román and Busch 2015: 18), and at the same time are not conveying that this is an issue in which the wider public need to take agency.

A number of studies have investigated the use of metaphors to frame climate change in different types of communication, including policy documents (Shaw and Nerlich 2015), the media (Romaine 1997; Atanasova and Koteyko 2015), and public discourse generally (Lakoff 2010). The focus of this work tends to be on the implications of different metaphors for how problems, solutions, and scientific debates are presented, and on the potential consequences for the opinions and actions of the general public (see Koteyko and Atanasova 2017 for an overview). In particular, reservations have been expressed about the suitability of the 'greenhouse' metaphor as a way to explain global warming and the problems it causes (Romaine 1997; Nerlich and Hellsten 2014). A smaller number of studies have considered the use of metaphors for climate science by school-age students. Shepardson *et al.* (2011) investigated mental models of the greenhouse effect in 12–13-year-olds, using the students' drawings and written explanations of them. Their analysis led to the identification of five mental models; the textual explanations of these models include a number of metaphors, such as 'bounce' and 'trap'. Niebert and Gropengiesser's studies (2013, 2014) included metaphor analysis of interviews with German secondary school students and of research reports and textbooks, alongside qualitative content analysis. The analysis suggested variance between expert and student understandings of the mechanisms of climate change. Both groups use a container metaphor, and the term 'greenhouse' is present in both groups' discourses. Students' use and understanding of abstract ideas seem to be limited by their concrete experience (Niebert and Gropengiesser 2014), which leads to misunderstandings; for example, that the greenhouse effect traps heat through a thin barrier analogous to a pane of glass.

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While these studies have generated important insights into students' conceptions, the understanding and application of the notion of metaphor is vague from an applied linguistic perspective. Niebert and Gropengiesser write 'We identified a metaphor by a term or sequence that has or may have more than one meaning' (2013: 285), while Shepardson *et al.* (2011) searched for conceptual models rather than metaphors per se. No large-scale corpus linguistic approach to metaphor use in texts about climate change produced for and by school students is reported as yet. This is a gap: a linguistic metaphor approach has been shown to generate insights into public understandings and attitudes in other important areas, such as cancer and end-of-life care (Semino et al. 2016, 2017). The research questions that this study attempts to answer are:

- What metaphors are used by academic researchers, authors of popular and educational science materials, and school students to write and talk about climate change?
- Do the school students use climate change metaphors differently from the other two groups?
- What understandings (and misunderstandings) are suggested by the metaphors used by school students?

4. CONTEXT

The study took place in England, where most state schools are obliged to follow a National Curriculum specifying what should be taught at each age and level of schooling (https://www.gov.uk/national-curriculum). The current National Curriculum for primary schools (ages 4–11) (Department for Education 2013) does not contain explicit mention of climate change. Most students in England start their secondary education aged 11, and until 14, in most cases, are in Key Stage 3 (KS3), where all subjects are compulsory. Key Stage 4 (KS4) leads to national examinations normally taken at the age of 15 or 16. The National Curriculum for secondary schools (Department for Education 2014) includes climate change in the KS3 Geography and Chemistry curricula. The direction for coverage in KS3 Chemistry is as follows:

> pupils should be taught about [. . .] the production of carbon dioxide by human activity and the impact on climate (2014: 62, 64).

In KS4, climate change is covered in what students should be taught about in the 'Earth and atmospheric science' section of Chemistry. This is studied by all students, though sometimes as part of a general Science qualification rather than as a separate named subject. Students should be able to:

- describe the greenhouse effect in terms of the interaction of radiation with matter;
- evaluate the evidence for additional anthropogenic causes of climate change, including the correlation between change in atmospheric

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carbon dioxide concentration and the consumption of fossil fuels, and describe the uncertainties in the evidence base;
- describe the potential effects of increased levels of carbon dioxide and methane on the Earth's climate and how these effects may be mitigated, including consideration of scale, risk, and environmental implications (Department for Education 2015).

The direction that students should consider uncertainties in evidence for additional anthropogenic climate change is not consistent with thinking in the scientific community. There is more extended coverage in the KS4 Geography curriculum. Unlike Chemistry, which has to be taken either as a stand-alone subject or a component of a Science qualification, Geography is not a compulsory subject at this stage, though it is popular. In the summer of 2015, the Geography GCSE (the KS4 terminal examination) was taken by 36.6% of students in the relevant age group (Gill and Williamson 2016).

5. DATA AND METHODOLOGY

5.1 Corpora

Five corpora were built for this project. This article reports on a linguistic metaphor analysis of three of them, composed as shown in Table 1.

The relationship between the corpora can be described as one of 'recontextualization' of scientific knowledge (Linell 2009; Semino et al. 2013). The Academic Corpus represents expert knowledge of climate science; the Materials Corpus reproduces some of this knowledge in ways that are intended to be appropriate for young people; and the Interviews Corpus reflects some school students' understandings of this body of knowledge, as expressed and developed in focus group interviews.

In compiling the Academic Corpus, articles published after 2010 were not included because it was assumed that there is a delay in cutting-edge research reaching materials accessed by young people. The three journals were recommended by researchers in the departments of Energy and Environment at Leeds and Lancaster Universities.

The Interviews Corpus consists of 41 transcribed focus group interviews with school students aged between 11 and 16. We worked with four state schools (i.e. non-fee-paying) from the north of England, all of which follow the National Curriculum, briefly described above. The schools differed in the socio-economic profile of their students. All interviewees were native speakers of English. In England, the year groups at this stage of schooling are referred to numerically from Year 7, in which students are 11–12, through to Year 11, in which students are 15–16. The interviews were conducted by one of the authors on school premises with groups of four to six students chosen by a science teacher, and lasted, on average, 20 minutes. Each interview comprised students from a single year group; that is, ages were not mixed. This was for the convenience of the host schools, who released groups of students from a

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Table 1: Corpora of discourse on climate change

Number	Name	Tokens	Content
1	Academic	250,733	Articles published between 2000–2010 in the journals *Climate Change, Global Environmental Change, Nature*
2	Materials	206,976	Popular and educational materials about climate change from 2005–2015: textbooks, revision guides, teacher packs, educational and popular science websites
3	Interviews	87,929	Transcribed focus group interviews with school students aged 11–16

single class at a time. The questions used are given in the Appendix. Consent was obtained and data processed and stored in accordance with the University of Leeds ethical procedures. Students were asked a number of questions about their knowledge of climate change and the greenhouse effect. They were also asked where they would look if they wanted more information on these topics. The websites and texts that they mentioned were included in the Materials Corpus, the last to be compiled. The Materials Corpus also contains educational material from books, such as revision guides, and websites, such as BBC Bite Size, that were recommended to us by science teachers from the schools in separate interviews.

5.2 Analysis

The corpus software Sketch Engine (Kilgarriff *et al.* 2014) was used for the analysis. The three authors analysed sample sections of the data together. The bulk of the analysis was then conducted by one of the authors, with discussions of further samples with the other two. The first step was to extract a list of lemmas in order of raw frequency for each of the three corpora using the 'word list' facility. For the Academic and Materials Corpora, the analysis proceeded from the most frequent lemmas down to the point where a lemma appeared less than 200 times per million tokens. In terms of frequency, this was reached at 61 citations for the Academic Corpus, and at 48 citations for the Materials Corpus. For example, in the Academic Corpus, the lemma 'SHORT' occurs 61 times, or 202 times per million tokens and was examined; in the Materials Corpus, 'OPEN' occurs 48 times or 200.31 per million tokens and was examined. Beyond this point, only lemmas which were found to be of interest in one of the other corpora, or which appeared in collocation with other lemmas of interest, were studied. The Interviews Corpus is much smaller, and all lemmas were examined down to and including those that occurred 5 times in total (46 times per million tokens).

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The full concordances for all candidate lemmas, several hundred for each corpus, were examined to determine whether their use in the texts was metaphorical, non-metaphorical, or a mix of both. Identifying metaphors in discourse is recognized as being contentious; the analysis was based on the Metaphor Identification Procedure ('MIP', Pragglejaz Group 2007). This requires the analyst to identify the 'contextual' or discourse meaning of each lexical unit in a text. The 'basic' meaning of the lexical unit is then considered, with the help of a dictionary if necessary, and a decision is made as to whether the contextual meaning is the same or different to the basic meaning. If it is different, and if the relationship between the two meanings is considered to be one of comparison, the contextual meaning is labelled as a metaphor. For example, the contextual meaning of 'greenhouse' in the Academic Corpus is the scientific meaning found in the expression 'greenhouse effect'; its basic meaning is a glass structure for growing plants in. The relationship between the two meanings is one of comparison, so the Academic Corpus use was categorized as metaphorical. To take a less intuitively clear example, the contextual meaning of 'model' found in the Academic and Materials Corpora refers to a description that has a theoretical status, and that is used to generate predictions, of a scientific process or system. The basic meaning is a miniature replica of a concrete entity. Applying MIP, we concluded that the contextual meaning is metaphorical.

MIP involves reading the entire text and considering every lexical unit. As noted, in this study only the more frequent lexical lemmas, rather than every lexical unit, were examined. The Interviews Corpus, which is relatively small, was read in full by all three authors. For the other two corpora, reading entire texts was not feasible, but the concordance window and, where necessary, additional co-text were found to be sufficient to determine contextual meanings.

Kimmel notes that the metaphor analyst may try to capture *all* metaphors in their corpus, but that, more usually, 'a restriction to one or a small set of domains makes sense because the researcher wants to maintain a thematic focus' (Kimmel 2012: 5). Given our research questions, we took the second of these approaches, and restricted our qualitative analysis to metaphors that were used to write or talk about any aspect of climate science, including the methodology for researching and reporting it, climate change itself and the scientific processes involved, and its consequences. There is inevitably a grey area, of metaphors that are used to write and talk about science more broadly, and we took an inclusive approach to these. Frequent metaphorical uses that we eliminated from study at this point include *way* and *point*, which are frequent in most registers (Stubbs 2002, 2009), and uses of some delexical verbs and a number of grammatical words, such as prepositions.

A number of similes were also identified. In terms of MIP, similes involve the 'basic' meanings of words. For example, in 'the earth is like a greenhouse', from one of our interviews, 'greenhouse' is used in its literal meaning.

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However, like metaphorical expressions, similes involve the comparison of unlike entities, and were therefore included in the analysis.

Concordance data for all the domain-specific metaphorically used lemmas above our frequency cut-off point were then analysed qualitatively, using established techniques in the corpus study of metaphorical meaning (Deignan 2005; Semino 2008, 2017; Tissari 2017). Metaphorical use across the three corpora was compared. This article discusses the comparison between the students' metaphor use and the use of the same metaphors in the other two corpora. The analysis therefore takes the students' use of metaphor as its starting point (tackling our second research question). The students' use of metaphorical meanings in the Interviews Corpus was then considered for its consistency or otherwise with expert knowledge about climate change (tackling our third research question).

6. METAPHORS IN THE THREE CORPORA

6.1 Most frequent metaphors in each corpus

Our first research question asked what metaphors are used by academic researchers, authors of popular and educational science materials, and school students to write and talk about climate change. Tables 2–4 show the 10 lemmas used most frequently as metaphors to write or talk about climate science in each corpus. In some cases, the same lemmas were also used non-metaphorically, including as similes, as shown in the fifth column of each table.

We do not draw any evaluative conclusions about the comparative frequencies of different metaphors between the three corpora. Clearly, while the broad subject matter is similar, the specifics of the topics of each corpus are different; there is not an expectation that the same metaphors would be used with similar frequencies.

The most frequent climate science metaphors for each corpus suggest some of the key themes in and differences between the corpora. For the Academic Corpus, the very frequent uses of 'model' and 'scenario' reflect the concern in the expert literature with the methodology of researching climate change. It is common in these texts to evaluate and compare projected models of the climate and greenhouse warming, seen in citations such as:

> . . .precipitation varies much more in space and time and is notoriously much harder to simulate correctly in models.

Similarly, metaphorical 'scenario' generally refers to one of a small number of possible sets of future conditions which serve as references for sets of predictions. Metaphorical uses of 'response' refer to the reaction of one part of the climate system to a change in another part. In this corpus, 'greenhouse' is the 22nd most frequent metaphor, in contrast to its higher ranking in the Materials and Interviews Corpora. This reflects the more wide-ranging coverage of all

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Table 2: Metaphors of climate science in the Academic Corpus

Rank	Lemma	Metaphorical use: raw frequency	Metaphorical use: per million tokens	Non-metaphorical use: raw frequency	Total citations of lemma
1	Model	980	3908.5	–	980
2	Impact	471	1878.5	–	471
3	Scenario	454	1810.7	–	454
4	High	430	1715	54	484
5	Response	416	1659.1	33	449
6	Value	365	1455.7	19	384
7	Low	291	1160.6	53	344
8	Base	280	1116.	6	286
9	Level	268	1068.9	90	358
10	See	246	981.1	1	247

Table 3: Metaphors of climate science in the Materials Corpus

Rank	Lemma	Metaphorical use: raw frequency	Metaphorical use: per million tokens	Non-metaphorical use: raw frequency	Total citations of lemma
1	Greenhouse	529	2555.9	38	567
2	Rise	345	1666.9	199	544
3	Impact	276	1333.5	–	276
4	Level	222	1072.6	243	465
5	Lead (li:d)	221	1067.8	2	223
6	Find	192	927.6	–	192
7	High	190	918	53	243
8	Release	182	879.3	3	185
9	Cut	125	603.9	28	153
10	Growth	73	352.7	23	96

aspects of climate change in the Academic Corpus; texts in the Materials and Interviews Corpora are more specifically focused on the greenhouse effect.

'Go' is frequent in both the Materials and Interviews Corpora, but for different reasons; in the Materials Corpus, it has a range of non-literal meanings not specific to climate science, often as a delexical verb. We did not consider these to be domain-specific and therefore did not include 'go' in Table 3. However, in the Interviews Corpus, most of the metaphorical citations were

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Table 4: Metaphors of climate science in the Interviews Corpus

Rank	Lemma	Metaphorical use: raw frequency	Metaphorical use: per million tokens	Non-metaphorical use: raw frequency	Total uses of lemma
1	Go	388	4410.1	112	500
2	Greenhouse	161	2172.2	72	233
3	Cap (in 'ice cap')	94	1069	–	94
4	Release	89	1012.1	–	89
4	Trap	89	1012.1	–	89
6	Lead (li:d/)	38	432.1	–	38
7	Slow	36	409.4	–	36
8	Bounce	33	375.3	–	33
9	Blanket	30	341.1	5	35
10	Chain	30	341.1	–	35

accounted for by two domain-specific uses: first, 'cease to exist', in citations such as:

> ... certain plants that we eat them as well obviously, then we wouldn't have enough to eat because all them would be going.

The second use is the (non-standard) phrase 'go extinct', for example in the following:

> ... reproducing would be too hard because they wouldn't be able to, because of the conditions and stuff so animals would go extinct.

'Lead' is frequent in the Materials and Interviews Corpora because it signals a cause–effect relationship, in citations such as:

> This could lead to increased desertification. (Materials Corpus)

> That could lead to, like floods going on in the world. (Interviews Corpus)

This use is also found in the Academic Corpus, where it is the 15th most frequent metaphor. In the Academic and Materials Corpora, there are a number of metaphors associated with measurement, such as 'level', 'rise', 'high', and 'low'. These are also used literally, especially to write about sea levels. Our quantitative analysis gave an overview of themes in climate science discourse in our three corpora. We used the quantitative findings for the Interviews corpus as the starting point for qualitative analysis of metaphor use.

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7. QUALITATIVE ANALYSIS OF FREQUENT DOMAIN-SPECIFIC METAPHORS IN THE INTERVIEWS CORPUS

Our second and third research questions were:

- Do the school students use climate change metaphors differently from the other two groups?
- What understandings (and misunderstandings) are suggested by the metaphors used by school students?

To tackle these, we conducted a further, more detailed analysis of the concordances of all of the most frequent lemmas that were used with domain-specific metaphorical meanings in each corpus. Here, we discuss our findings from the perspective of the Interviews Corpus, taking examples from the most frequent domain-specific metaphors of the major frequency patterns found. We begin by analysing the use of 'greenhouse', as arguably the most salient domain-specific metaphor, and second most frequent in the Interviews corpus (after 'go', discussed above). 'Greenhouse' is frequent in the other two corpora; as Table 3 shows, it is the most frequent domain-specific metaphor in the Materials corpus. It is also frequent in absolute terms in the Academic Corpus (123 occurrences), albeit at a lower rank in relation to other metaphors (22nd).

A group of metaphors in the Interview corpus also occur frequently in the Materials corpus but are very infrequent in the Academic corpus. These include 'cap', which occurs 45 times (217 per million words) in the Materials corpus, but only 3 times in the Academic corpus (12 per million words). This reflects a concern with the physical environment found in students' discourse and materials; we also found this concern reflected in the frequency of words to describe animals such as 'penguin' and 'polar bear' in both corpora. However, as a highly conventionalized metaphor with concrete reference, this is not especially informative about students' understandings of the science. Other words used frequently in the Interviews and Materials Corpora but not the Academic corpus include 'release', which is in the top 10 most used metaphors in the Interviews and Materials corpora, but is around 10 times less frequent in the Academic Corpus (99 citations per million words, compared with 879 and 1,012 citations per million words in the Materials and Interviews Corpora, respectively), as well as 'trap', 'lead' (briefly discussed above), 'blanket', and 'chain'. We discuss 'release' in detail below.

A third, small group are highly frequent in the Interviews corpus but not frequent in the other two corpora. This group comprises 'bounce', 'band', and 'barrier'. 'Bounce' and 'barrier' occur in many of the 41 interviews; we discuss 'bounce' below. In contrast, all the citations of 'band' occur in a single interview, appearing to exemplify a phenomenon first described by Cameron (2007): the development of metaphorical meaning within a discourse. She writes 'Metaphor works cognitively and pragmatically at the micro or local timescale, as ideas are challenged, negotiated and accepted' (Cameron 2007:

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218). We discuss the development of meanings of 'band' below, suggesting how this process appears to lead to some misunderstanding of climate science.

7.1 Greenhouse

In the Academic Corpus, 'greenhouse' occurs 124 times, in 123 of these as a noun modifier. The most frequent right collocate is 'gas(es)', a collocation which accounted for 103 citations. 'Greenhouse gas' is itself sometimes part of a longer noun group, such as 'greenhouse gas concentrations', or 'greenhouse gas mitigation strategy'. This seems to be a highly technical meaning which has become restricted in its lexico-grammatical patterning. The abbreviation 'GHG', standing for 'greenhouse gases', also occurred 14 times, further evidence for a technical, restricted meaning. The Academic Corpus contains no citations of 'greenhouse' used with the basic meaning of 'glass structure'. The writers and readers of these texts probably do not consider their technical use to be metaphorical; as noted above, scientists tend to regard established metaphors in their field as technical terms no different from others (Knudsen 2003).

In the Materials Corpus, 'greenhouse' occurs 541 times, of which 503 are metaphorical, and 38 literal, that is referring to a glass structure. Most of the metaphorical citations follow similar patterns to the Academic Corpus; the most frequent right collocate is 'gas(es)', followed by 'emissions'. There are exceptions: two citations of 'greenhouse earth' and one of 'greenhouse world'. Of the 38 literal citations, 15 are similes, including:

> The earth's atmosphere acts like a greenhouse made of glass.
>
> Like the glass in a greenhouse, the gases stop energy escaping.

The remaining 23 literal citations are from extracts encouraging students to compare the world with a literal greenhouse, in various ways, as in the following:

> What happens when you go into a greenhouse on a sunny day? It's hot, isn't it? That's because the glass in the greenhouse traps the heat from the sun. This gas carbon dioxide does the same in the earth's atmosphere.

In the Interviews Corpus, 'greenhouse' occurs 161 times as a metaphor, often with the same range of collocates as in the Academic and Materials corpora. In some citations though, it is used in lexico-grammatical patterns not found in the other corpora. (Students' year numbers are given as an approximate indication of age.)

> Global warming is caused by erm, the greenhouse, and the climate change is caused by humans. (Year 7 student)
>
> Carbon emissions are getting added to the atmosphere which because the greenhouse outer layer that increases the greenhouse effect that's changing, melting the ice-caps. (Year 11 student)

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The non-metaphorical use of 'greenhouse' also occurs 72 times in the Interviews Corpus, of which 30 are similes, as in the following:

> It's almost as if the earth is like a greenhouse because when we're burning fossil fuels it gives off like pollution, greenhouse gases, and they get trapped in our atmosphere... (Year 8 student)

Sometimes the students make direct comparisons with their experience of a literal greenhouse:

> my mum has a greenhouse so I kind of like refer back to that. It's where like, because at certain heights the sun is able to get into like the glass... (Year 8 student)

This same student continues, developing the comparison:

> it's like, the earth is covered in like lots of glass panels but we just can't see them, because the sun's projecting into them. It doesn't, it won't come out, it'll just keep coming in and when it tries to get out, it'll just bounce off the roof and down in a continuous loop. (Year 8 student)

This analogy is found in other interviews, from students of different ages and from different schools:

> The earth is like the plant, and the CO2 is making like a glass shelter around it, and it's trapping heat in. (Year 7 student)

> It's just like a greenhouse innit? It gets really hot inside cos of all the glass and it's like these gases are like doing that in the atmosphere. (Year 11 student)

The concordance data from the three corpora suggest that 'greenhouse' has become a restricted technical term for experts, with little or no connection to the literal meaning, but that educational texts encourage students to think about the literal meaning and the grounds for the comparison. Citations in the Interviews Corpus suggest that students do indeed do this, arguably because of the influence of these texts, because their teachers encourage them to, or because they are using strategies to make sense of a metaphor, or for all three reasons.

The term 'ozone' is found 106 times in the Interviews corpus, though the interviewer did not ask about the ozone layer at any point. In several citations, there is clear evidence that students have linked the ozone layer with the 'greenhouse':

> the actual greenhouse is the ozone layer (Year 8 student)

> greenhouse gases damage the ozone layer which makes the earth warmer like it's in a greenhouse so it's. a greenhouse is warmer than like, on the outside, (Year 10 student)

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In terms of scientific accuracy, students correctly infer that the greenhouse effect leads to warming, because heat is trapped. However, the students repeatedly draw a further inference (as was the case in the studies reported by Niebert and Gropengiesser 2014, above), that greenhouse gases form a thin layer around the planet which does not let heat out. This is incorrect: greenhouse gases are dispersed rather than forming a discrete layer. There may be at least two other reasons for this misunderstanding: the students will almost certainly have seen one of the many diagrams of the greenhouse effect in textbooks and on the Internet, in which accumulating greenhouse gases are shown as if in a discrete layer, encircling the planet. Secondly, our data also indicated confusion between the greenhouse effect and what may be more accurately described as the depletion of the ozone layer. To what extent this misconception matters for students at this level of their education is a question for science educators.

7.2 Release

In all three corpora, 'release' is used metaphorically to refer to a previously enclosed substance, typically greenhouse gases, being allowed to move. In the Interviews Corpus, it is the fourth most frequent domain-specific metaphor, and the eighth most frequent in the Materials Corpus. As noted, it is much less frequent in the Academic Corpus, with 25 citations of the lemma. Here, when 'release' is in the active voice, the subject of the verb is a process, and the object is a greenhouse gas as in the following citation, or less frequently, heat:

> ... the biological process of denitrification releases nitrous oxide.

The verb is sometimes used in passive voice, with the same elements of meaning.

In the Materials Corpus, 'release' is used in the same way. There is some evidence that the metaphor is extended, in Knudsen's terms, 'opened up' (Knudsen 2003), where collocates of the literal use seem to be used with the same metaphorical mapping, as seen with 'locked', 'trapped', and 'freed' in the following citations:

> ... as the tree decays, the carbon locked inside is gradually released back into the atmosphere.

> ... large quantities of methane stored in the frozen tundra of the north may be released. Also methane trapped in the sea bed may be freed by temperature rises.

Concordances from the Interviews Corpus show that some students use 'release' in the same way as the expert writers in the Academic and Materials Corpora, as in this citation:

> We're burning the fossil fuels so it releases the greenhouse gases (Year 10 student)

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In some citations, the metaphor is used in the same way, but the students clearly have less precise knowledge:

> Is it where the amount of like, toxins released into the air, they trap the heat inside (Year 10 student)

In this corpus, a much wider range of entities are 'released' than in the Academic and Materials Corpora, including 'a smog', 'chemical waste', 'particulates', 'gas', 'pollution', 'sunrays', and 'energy'. In some citations, students use the word very vaguely, giving the impression that they do not have a precise understanding of what the subject and object of the process are:

> if we're recycling stuff like the landfills, I don't know, it releases something like, you know, less landfills and less pollution and stuff like that. (Year 10 student)

> It's getting thicker because erm, there's more pollutants and they're like carbon dioxide, so cos it's getting thicker, less oxygen, less gases, like bounce back off. So they're getting less released so there's holes in there, which makes it more warmer. (Year 10 student)

In these cases, it seems possible that the students have encountered the word 'released' in their science classes and other material on climate change, and remembered it, perhaps because its other metaphorical use (to 'release' a film, book, or report) and its literal use are familiar to them. They may not, however, have completely understood the context and meaning intended in the scientific use of the term, which has led to only a vague understanding of the scientific process described. Similar patterns were found in the analysis of other metaphorical terms that have literal meanings familiar to students, such as 'impact', 'balance', and (food) 'chain'.

7.3 Bounce

'Bounce' occurs once in the Academic Corpus, in the phrasal verb 'bounce back' meaning 'recover'. It occurs 3 times in the Materials Corpus; one of these is 'bounce back' ('recover'), one refers to radio signals, and one to the sun's rays bouncing off the atmosphere. In the Interviews Corpus, however, 'bounce' occurs 33 times, with a metaphorical meaning derived from the literal 'rebound from a hard surface'. This use is found in data from all four schools and across all year groups. Entities that 'bounce' in the Interviews Corpus are shown in Table 5. Each of the example citations is from a different interview, and students from three of the four schools are represented.

This metaphor may occur in teachers' spoken explanations, which are not included in our data set. It is also possible that students are referring to the many diagrams of the greenhouse effect in textbooks and websites which show heat or greenhouse gases travelling out from the earth's surface and being apparently reflected from a hard surface around the edge of the atmosphere. 'Bounce' would be an accessible way to lexicalize this, especially for students

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Table 5: Subjects of 'bounce' with examples in the Interviews Corpus

Entity	Number of occurrences	Example
Sunrays/Rays/Light	17	... the sun gives off rays, and then, they bounce off the earth. (Year 9 student)
Heat/Warmth/Steam	8	... cars and boats and planes, which are letting off other like steam or heat, that's bouncing back from the, making us warmer. (Year 7 student)
CO_2	4	... the CO2 can't get out and it like bounces off it and goes into the earth. (Year 7 student)
Gases/Smoke	2	the smoke just bounces straight off again and comes back down (Year 7 student)
UV light	1	... the UV light comes in, then it like tries to bounce off but the ozone layer acts like a tight gases, so it like keeps it in (Year 10 student)
Infrared radiation	1	... infrared radiation can't get back out ... it bounces off the ozone layer. (Year 10 student)

aged 11–16, who will be regularly involved in sports such as football and tennis, and ball games, and therefore immediately familiar with the literal meaning. This would suggest that the metaphor is creatively coined, or translated from the visual and/or physical to spoken mode. Another metaphorical use unique to the Interview Corpus, and probably originating in the same way, is 'barrier', as used in:

> 'there's a heat barrier sort of round the earth'. (Year 7 student)

7.4 Band

We now examine the development of one metaphor as used in the course of a single interview. From a frequency point of view, 'band' contrasts with the three other metaphors we have discussed. It was not found at all in the Academic and Materials corpora, and occurs 8 times in the Interviews Corpus. These eight citations, however, were not distributed across the interviews, but all occurred in the same interview. Of these, only five meet the test for metaphoricity, but all eight signal the same comparison. The six participants were aged between 11.5 and 12.5 years.

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Excerpt 1

Turn number	Speaker	Utterance
001	Interviewer	Can you tell me what you know about climate change
002	F01	Erm like it's erm, things that we do affect the environment. So like if you use lots of CO_2 it like might affect the polar bears and like melt their ice-caps and stuff.
003	M01	Erm, basically, CO_2 comes out of a car, it goes to the sky and stops there, and instead of letting heat straight out, like makes it bounce back in, and warm the world up.
004	F02	Yeah this is what he means, like, there's like a band around the world and it like lets some of the CO_2 out, and then it like goes, some of it goes out but some if it stays in cos the more CO_2 that we're using, erm, it's like the band gets tighter and tighter, and so like, until no air can, like CO_2 can get out, and it like bounces back and goes in the earth and then it warms the earth and then it melts the ice-caps.
005	Interviewer	Why is climate change happening?
006	F01	It's because of like, we've got more pollution from cars and like erm, transport, and erm, different like technical things, like technology.
007	Interviewer	Why is that causing climate change?
008	F01	It's to do with the erm, band, like the, a bit like a bubble round us, erm, that's like getting thicker kind of thing, and it's not letting as much out, as much CO_2 out.
26 turns later, the students talk about how they would explain climate change to a younger pupil.		
035	F02	Like there's like a rubber band around the earth and then we're in the middle of it. And then there's this like thing called CO_2 and it comes out of cars and stuff. It's like pollution from factories and stuff like the smoke that you see and stuff that's CO_2. And then, it like goes up, yeah.
036	F03	It goes up into the air and bounces off the rubber band and warms up the world and there'll be different effects from that.
037	F02	Yeah and we're using more CO_2, so the band gets tighter and tighter like, when you put a rubber band around your finger or something, it gets tighter and tighter. It's like that around the earth, and then eventually the CO_2 can't get out and it like bounces off it and goes into the earth and warms the earth up.
5 turns later, the students are trying to explain the greenhouse effect.		
43	F03	It's like erm, erm, with all the pollution that's going up into the air, that erm like, erm, the like band around the earth, like erm getting tighter so it's not letting things in, so it's like the world like trapped in a giant greenhouse and it's just getting hotter and hotter.

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'Band' is introduced by a female student, F02, in turn 4, to rephrase her fellow student's attempt to describe how increased CO_2 leads to greater amounts of heat being retained in the earth's atmosphere. The term 'band' may be the student's paraphrase of 'layer' (which, as noted above, is a slightly inaccurate conception). F02 uses 'band' twice in utterance 4, the second time saying that the band can get tighter. This is not a feasible property of a layer of gases, but it is something that can readily happen to the kind of band that is used for holding everyday objects together in bundles. Subsequent uses are with the definite article, indicating that the 'band' now has the status of shared knowledge within the group. The student who originated the use, F02, returns to the term 26 turns later, this time calling it a 'rubber band'. Rubber bands are inexpensive, concrete, everyday objects likely to be highly familiar to school students, unlike the related but abstract meaning of 'band' meaning 'layer of gases' that seems to have been intended when the term was first used in turn 4. This slide between related meanings of a word again suggests the insecurity around terminology discussed above. In these turns, the students are suggesting explanations for a younger pupil, which might also lead them to refer to a concrete everyday object. In all, three of the six students present at the interview use this term, which is not used elsewhere in this or the other corpora. The students' use, and repetition of the term, leading to developing a shared understanding of it within the local context, is consistent with Cameron and Deignan's findings, that metaphors are sometimes created locally and develop a shared meaning within a specific discourse event (Cameron and Deignan 2006; Cameron 2007, 2008).

In terms of scientific accuracy, F02's statement at the beginning of turn 4, that the 'band' allows less of something to escape, resulting in the planet becoming warmer, has something in common with current scientific understanding. Less accuracy is seen in the references to the band 'getting tighter', at the end of turn 4, turn 37, and turn 43. In turn 37, where F02 draws on her concrete, possibly physical experience of a rubber band wrapped round a finger, the extended account of how increased CO_2 emissions lead to warming is very inaccurate. In this case, metaphorical reasoning seems to contribute to a serious misunderstanding of a topic which the group of students had a relatively vague understanding of at the beginning of the interaction.

8. CONCLUSION

Student discourse as represented in the Interviews Corpus uses some of the same metaphors as experts, but our detailed qualitative examination suggests that sometimes the meanings expressed are different. It seems that students tend to make extensive use of their knowledge of literal referents of metaphorical terms, as is consistent with Cameron's (2002) findings. Our examination of the Materials Corpus suggests that this tendency is encouraged by the educational materials that they access. This has advantages and drawbacks: it is pedagogically sound to encourage students to engage actively with texts and

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terminology, and their discussions of 'greenhouse' in the Interviews Corpus show they are doing this. As we have shown though, students sometimes fail to realize that this term has a technical and non-negotiable meaning for scientists, and they also tend to draw inferences from the metaphorical use that are not consistent with established expert understandings of the relevant phenomena.

In some cases, students seem to use metaphors as an attempt to display knowledge that seems, on examination of context, to be vague or almost non-existent. This problem could be missed by teachers working under pressure; they may note the use of terminology, but not have the time to read or listen to their students more closely to see whether it is used in a way that shows real understanding.

Our findings are consistent with previous work that has compared expert and non-expert texts on science, showing that the metaphors that are conventionalized and have taken on a specific and technical meaning for scientists are opened up and extended by non-experts. Additionally, we found that educational materials for young people make use of similes and refer to literal meanings in order to explicitly open up metaphors, apparently as a teaching tool, found in citations for 'greenhouse' in the Materials corpus. These metaphors are taken up and sometimes further extended by school students. This was the case for the students' use of 'greenhouse'. Less salient metaphors such as 'release', which nonetheless have discourse-specific meanings, are also interpreted by students with reference to their more general and already known meanings.

However, we found that not all the metaphors that students use can be explained as the result of a one-way flow from expert use through educational materials. Some metaphors are developed by the students themselves, and grounded in concepts of more immediate relevance to their own lives: citations in the Interviews Corpus show that students are willing, even enthusiastic, to frame their understandings with metaphors such as 'bounce' and 'barrier', and in the case of 'band', to extend this creatively. As we found though, this can be at the expense of scientific accuracy.

Our linguistic approach complements existing studies of school students' understandings of climate change, which, as noted, have largely been analyses of content and themes. By using corpus tools, we have been able to identify the most frequent metaphors and to select lemmas for detailed qualitative analysis in a principled way. More specifically, by analysing concordance data in detail, we have been able to see where students' accounts, and thus, presumably their understandings, differ from those of scientists. It is outside the scope of this article to offer recommendations on the deliberate choice of metaphors for pedagogical purposes; Grady (2017) explores this topic in the context of the public understanding of science.

The research could be developed and enriched with an examination of teacher talk and teaching aids such as PowerPoint slides from the classroom. It could also be taken forward with an examination of differences in students'

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knowledge and use of scientific and technical vocabulary. We also intend to take the research forward by analysing differences in vocabulary use between stronger and weaker students, in terms of academic performance. British secondary schools commonly 'set' students, that is place them in ability groups following test results. We found a very wide range in vocabulary use across the different sets, with top-set students having a strong command of scientific and technical vocabulary. This is an issue that merits further investigation.

NOTE

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APPENDIX

Questions asked in student focus groups

1 Please tell me what you know about climate change?

   1a. Why do you think climate change is happening?
   1b. Do you think that climate change is caused by human activities?
   1c. How does climate change affect the Earth?

2 What are the impacts of climate change on weather?
3 What are the impacts of climate change on water resources?
4 Where do you learn about climate change outside school?

   4a. For example, if you wanted to find out more after a lesson, or were revising or doing a project on it?
   4b. For example, TV programmes, magazines, websites etc

5 How would you explain climate change to a younger pupil?
6 What is the greenhouse effect? How might you explain it to a younger pupil?
7 What is the difference between climate change and global warming?
8 How do you think climate change might affect plants and animals?
9 What are the impacts of climate change on human health?
10 In what ways do you think climate change might impact upon our lives in the future?

   10a. How do you think it might impact on the lives of people in other parts of the world?

11 Is there anything we can do to help prevent climate change?
12 Can climate change be stopped?

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