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Stance and modals of obligation and necessity in academic writing

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Variation has been demonstrated in modal use between written and spoken registers and between disciplines. This article investigates variation within a discipline by comparing modals of obligation and necessity used in three science genres. Obligation modals project strong authoritative stance, thus contrasting with the tendency in academic writing towards tentativeness. The modal auxiliaries *must* and *should* and quasi-modals *have to* and *need to* are investigated using student writing from the BAWE (British Academic Written English) corpus and a corpus of published research articles. Findings include a dearth of obligation modals in the empirical genres (research articles and laboratory reports). Also a greater prominence was found of dynamic modal meaning (where necessity arises from circumstances) rather than deontic meaning (where the necessity arises from human authority or rules). A further finding is the prominence of objective meaning in the science register compared with the International Corpus of English (Collins 2009a).

Keywords: obligation modals, stance, science writing, student writing, corpora

1. Introduction

The literature on modality has shown differences in the use of modal auxiliaries between spoken and written registers (Biber 2006; Collins 2009a), and between different varieties of English, such as British and Australian English (Collins 2009a). Differences have also been explored between the use of modals in different disciplines (Hyland 2005). However, variation between registers is found not only between disciplines, but also within them. In this article, I explore variation

in the use of modal auxiliaries between three written academic science genres.¹ Two of the genres studied (student laboratory reports and science research articles) share a purpose: that of reporting experimental results; however, they differ in reader status (expert and novice) and reader writer relationship (students write laboratory reports for instructors while researchers writing research articles to be read by peers). A further comparison is made between two student genres: laboratory reports and science essays; here the writer and the reader-writer relationship are kept constant, but the purpose for which they are written is varied (reporting experimental results compared to developing an argument). The article explores how this variation in purpose, reader-writer relationship, and writer status is associated with variation in writer stance.

In fact, modal auxiliaries have been shown in the literature to be prominent in the expression of stance. For example, Biber (2006:96) compares the use of necessity modals, possibility modals and prediction modals in written and spoken university registers. Hyland (2005) investigates the use of hedges and boosters between disciplines. However, neither study investigates register variation within a discipline.

To test such variation, I explore the contribution to writer stance of modals in three science genres. In order to investigate this variation in adequate depth, I limit my attention to modals of obligation and necessity, rather than considering all modal auxiliaries. Specifically I focus on the use of the four most frequent modal resources in my data, the modals *must* and *should* and the quasi-modals,² *have to* and *need to*.³

A further reason for this limitation to modals of obligation and necessity is my hypothesis that modals of obligation and necessity are likely to be an important resource for expressing meanings concerned with the exigencies of the experiment.

1. In this article, I draw on the Systemic Functional Linguistic distinction between register and genre. Register relates to language choices that speaker and writers make at the level of field (content), tenor (interpersonal relationships) and mode (organisation) (Halliday 1994). Genre is a social process, referring to “goal-oriented purposeful activities in which speakers engage as members of their culture” (Martin 1984: 25). To fulfil these goals within a particular cultural context, speakers and writers make typical register choices. This distinction is consistent with that made by Biber and Conrad (2019:16) where the linguistic characteristics of a register perspective are “any lexicogrammatical feature”, while the linguistic characteristics of a genre perspective are “specialized expressions, rhetorical organization, formatting”.

2. Following Collins (2009a) I use the term quasi-modals rather than semi-modals, also used in the literature.

3. No instances were found of the obligation modal, *need*, or of the quasi-modals *ought to*, *had better*, or *be to*. There was one instance of *have got to*, and two instances each of *be bound to* and *be supposed to*. These modals and quasi-modals were therefore not investigated in this study.

These include what the writer reports that they *had to* do, what *must* or *should* be done in the experiment, or what the organisms, molecules, apparatus etc. *need to* do. To investigate expression of these meanings, I consider the use of obligation modals in laboratory reports and in science students' essays, a genre that explains scientific ideas but does not focus on experimental work. In addition, I investigate the writing of established scientists, reporting on experimental work in published science research articles. I speculate that the obligations and necessities of experimental science will be reflected in similarities between research articles and laboratory reports, and in differences between laboratory reports and essays. To investigate the distinctiveness of the use of these modals in science writing, I compare my findings with Collins's (2009a) investigation of modal use in a general corpus of English, the International Corpus of English (ICE).

To investigate this hypothesis, I consider modals of obligation and necessity in three sets of data: student laboratory reports from the BAWE corpus, student science essays from the BAWE corpus⁴ and a small corpus of science research articles.

1.1 Stance in academic writing

Stance refers to writers' and speakers' expression of feelings, attitudes, judgements and assessments (Biber, Johansson, Leech, Conrad, Finegan, & Quirk 1999: 966). As Biber (2006: 87) notes, this makes stance particularly important in academic discourse, which seeks to assess the likelihood that propositions are factual, and to offer and justify opinions and attitudes about propositions.

A number of linguistic markers of stance in academic writing have been investigated. Hyland (2005), for example, focused on hedges, boosters, attitude markers and self-mention. Aull and Lancaster (2014) focused on hedges/boosters, code glosses, and adversative/contrast connectors. Hood (2004) considered the use of appraisal resources. Complement clause constructions have also been investigated as stance markers (Hyland & Tse 2005), as have noun and prepositional phrase constructions (Gray & Biber 2012) and stance adverbials (Gray & Biber 2012).

As Biber (2006) outlines, stance may be expressed lexically using verbs (e.g., *despise*), nouns (e.g., *paragon*) and adjectives (e.g., *virtuous*). It may also

4. The term 'essay' is widely used in tertiary education for almost any piece of writing students do. The constructors of the BAWE corpus, however, report that they limited this descriptor to student texts that developed an argument, using language such as "I will evaluate..."; "I will discuss whether..."; "I will try to question"; "In order to challenge..." (Gardner & Nesi 2013: 35). An example from an Engineering essay included in the data in this article is: "The definition of a professional engineer is not clear, and has been the subject of debate for many years. Below are four suggestions justifying what makes a professional engineer which I will discuss and conclude which I feel is most accurate. The first argument suggests that..."

be expressed by the use of stance adverbials (e.g., *obviously*, *fortunately*), and complement clauses framed by either verbs (e.g., *we believe that...*), nouns (e.g., *there is no doubt that ...*) or adjectives (e.g., *it is possible that...*). Stance may also be expressed by the use of modal verbs (Biber 2006:87–91). The focus of this study is modals and quasi-modals of obligation and necessity: specifically, the study examines the use of two modal auxiliaries (*must* and *should*) and two quasi-modals (*have to* and *need to*).

The use of these obligation modals in relation to projecting writer stance is likely to vary substantially because of variation firstly in whether the speaker's perspective is subjective (that is, the speaker commitment to the proposition), or whether speaker perspective is objective, (that is, there is no speaker commitment to the proposition). This has an important influence on speaker's stance.

A second source of variation in speaker stance relates to the source of the obligation. One possible source of obligation is the speaker's own authority or that of rules and regulations (deontic modality); a second source of obligation is surrounding circumstances (dynamic modality); logical argument is a third possible source of obligation (epistemic modality). In order to clarify these distinctions, before moving on to discuss obligation modals in relation to stance, I discuss obligation modal meaning more generally.

1.2 Modal meaning

Three modal meanings that are commonly identified (Collins 2009a; Huddleston & Pullum 2002; Palmer 1979) are deontic, dynamic and epistemic meaning. In deontic modality, an authority such as a person, set of rules, or social conventions, imposes the obligation referred to in the utterance (Collins 2009a:22). Nuyts (2001:8) defines deontic modality as “an indication of the degree to which the ‘assessor’ (typically, but not necessarily, the speaker...) can commit him/herself to the state of affairs in terms of certain principles external to that state of affairs”.

In dynamic modality, the necessity referred to arises not from an authority but from the general circumstances. Verhulst, Depraetere, and Heyvaert (2013:210) include deontic and dynamic modality as types of root modality, both of which “refer to the factors that influence the actualization of a situation that is said to be necessary”. With deontic modality these factors are humans or rules and regulations, while with dynamic modality these factors are the circumstances surrounding the incident.

Epistemic meanings concern the speaker's perspective on the factuality of what they are talking about, their judgement about how likely what is being said is to be true (Collins 2009a:21). Nuyts (2001:21) defines epistemic meaning as the

speaker's "evaluation of the chances that a certain ... state of affairs under consideration (or some aspect of it) will occur, is occurring or has occurred".

1.3 Subjective and objective modality

A distinction is also made between subjective and objective modality. Subjective modality presents the speaker's perspective on the proposition in the utterance (Collins 2009a). Objective modality relates to a necessity that exists independently of the speaker (e.g., *to dissolve the solute, the solvent **needs to be heated***). Verstraete (2001:1509) observes that in semantic distinctions between subjective and objective modality, "the actual definition of the distinction usually boils down to whether or not the modal in question involves the speaker in the utterance".

However, he notes the practical difficulty in distinguishing between them. To do so, he uses the idea of modal performativity (Verstraete 2001:1517). This is analogous with interactive performativity in which, by using a performative, the speaker sets up a relationship with the hearer (e.g., obligation in the case of a promise, or authority in the case of an instruction). In modal performativity, a relationship is set up between the speaker and the propositional content rather than between the speaker and an interlocutor; subjective modality indicates the speaker's commitment to the proposition. By using epistemic *must*, the speaker commits him/herself to the truth of the proposition (e.g., *you **must** surely be finished now*). In using subjective deontic *must*, the speaker commits him/herself to the desirability of the action (e.g., *you **must** do your homework now*). In objective modality there is no speaker commitment and the necessity arises from surrounding circumstances.

Collins (2009a:36) notes the tendency "for the subjectivity/objectivity of deontic *must* to correlate with the person of the subject. The clearest cases of subjective deontic *must* are those where the subject is *you*... Similarly the clearest cases of objective deontic *must* are those with a 3rd person subject". This is merely a tendency however, and he quotes instances, such as (1) where *you* is the subject, but the speaker is not the deontic source:

- (1) Northern Building Society has informed us that you *must* return the Mercantile Mutual Insurance Policy ... (ICE-AUS Collins 2009a: 36)

Collins (2009a: 36) also cites instances such as (2) with a third person subject, but where the speaker is the deontic source:

- (2) You must keep them moist (...) That uh bud *must* not dry out at all. (ICE-GB Collins 2009a: 36)

Verstraete (2001:1525) concludes that deontic modals may be either subjective or objective, while dynamic modals are invariably objective. He states that epis-

temic modals are invariably subjective; Collins (2009a: 38), however, does identify objective epistemic modals, such as (3), stating that objective epistemic *must* expresses “logical certainty, a logical necessity based on what is known”; the speaker is confident that the conclusion they present is the only one possible. However, he reports that objective instances are a minority.

- (3) When you uhm therefore say that you agree with the sentence in practice the hysteric is not infrequently a malingerer too, it *must* follow from the very terms of that sentence, that sometimes there are hysterics who are not, malingerers too (ICE-GB S1B-070 14)

1.4 The source of the obligation

Of further concern in distinguishing deontic from dynamic modality and subjective from objective modality is who or what creates the obligation. Depraetere and Verhulst (2008) discuss the need for the source of authority creating the obligation to be clearly defined. The source may be subjective, where the source is “discourse internal” (Depraetere & Verhulst 2008): either the speaker or another discourse participant. In Example (4) the chairman of Sainsbury is the source of authority concerning Sainsbury’s obligation to provide good service:

- (4) The chairman of Sainsbury claims that the ‘...sheer amount of change in the business clearly distracted us from delivering as good a service as we *should*’. (Essay agriculture, BAWE6021c)

In academic writing, the source of authority can include researchers whose publications are cited. In the following Example (5), the cited authority, Thompson, is the source of the obligation:

- (5) The therapist needs to listen in order to understood [sic] what is being said and meant. They then *need to* confirm that they have heard and understood what was said and meant (Thompson 2002). (Essay health, BAWE3130a)

The source can also be objective, and here Depraetere and Verhulst (2008) distinguish three possible discourse external sources. The first is rules and regulations. In Example (6) the *rules* surrounding the *standard fuzzy set* **require** certain characteristics:

- (6) However the standard fuzzy set requires that the support for and against membership in a set *must* sum to one. (RA engineering, E1)

A second objective source is the obligation arising either from situations where the modal clause is necessary for a particular condition to be actualized or a particular purpose to be achieved (Depraetere & Verhulst 2008). These are expressed

either using conditional clauses (Example 7) or using *to*-clauses expressing purpose (Example 8). In (7), the condition in the modal clause (*uniformity of charge distribution*) must be in place in order for the conditional sub-clause (*the molecule being pushed through the pore by the force field*) to be actualized. In Example (8), the purpose (*HOT-DIW printing*) is the source of the necessity, and this will only actualize if the situation in the main clause (*the LCE ink possessing a strong thinning response*) is in place.

- (7) If the electric force field in the pore is to be used to systematically impel the molecule through the pore, the charge distribution along the protein *has to be* uniform. (RA engineering, E11)
- (8) To enable HOT-DIW printing of high fidelity architectures, the LCE ink *must* possess a strong sheer thinning response. (RA engineering, E8)

The third objective source of necessity arises from the circumstances surrounding the situation. In (9), the circumstances of size and complexity led to the necessity for manual analysis:

- (9) The size and complexity of Pucciniales and host datasets required that Jane program files for reconciliation analysis *had to be* done manually. (RA Biology, B1)

This study identifies deontic modality as obligation from either a discourse internal source or from rules and regulations, and dynamic modality as necessity arising from surrounding circumstances or from conditions or purposes.

However, as Collins (2009a: 36) points out and as (10) exemplifies, it is not always possible to identify who the source of the obligation is.

- (10) With all the galaxies moving away in proportion to their distance of separation, Hubble concluded that the universe *must be* expanding and indeed at one point in time the whole universe *must have* all been together. (Laboratory report physics, BAWE6094b)

1.5 Stance and obligation modals

The above discussion of modal meanings suggests that writer stance using obligation modals is likely to vary substantially because of variation in speaker commitment to the proposition. Hyland and Tse (2005: 181) discuss *must* as a booster, which “express[es] certainty and emphasiz[es] the force of propositions”. This characterization of *must* does generally reflect the meaning of deontic *must*; in Example (1) above, the Northern Building Society’s instruction that *you must return the Mercantile Mutual Insurance Policy* is quite forcefully expressed. However, epistemic *must*, which states the writer’s judgement about how likely what

is being said is to be true (Collins 2009a: 21), is correspondingly less forceful and certain. Example (10) notes Hubble's judgement about his observation that galaxies are *moving away*.

Dynamic *must*, as in (8), does not seem to express certainty, but rather describes the situation (*a sheer thinning response*) that needs to be in place for another event (*HOT-DIW printing*) to actualize. The same points can be made in relation to *should*, *have to* and *need to* as well.

Another factor influencing writer stance is modal strength. *Must*, for example, is stronger than *should* (Collins 2009a: 26; Verhulst et al. 2013). Verhulst et al. (2013: 211) also regard *have to* as being stronger than the medium strength modal, *should*. This can, however, vary pragmatically, with *must*, for example, functioning both in giving instructions (e.g., *you must stop writing now*) and in making suggestions (e.g., *you must come for dinner sometime*).

Academic writers need to be sensitive to how modals vary in strength, in order to avoid sounding overly authoritative. Collins's (2009b) study of the frequency of modals and quasi-modals in nine varieties of English found that, between the 1960s to the 1990s, the modals declined in use, while the quasi-modals increased. He explains these changes in frequency over time in light of a move to less forceful authoritative language. For example, he found the frequency of *should* (a medium strength modal) to be twice that of *must* (a strong modal).

Similarly, more objective modals allow the speaker/writer to project a more polite stance. For example, the frequency of *have to*, which Collins (2009b: 288) found commonly to be objective in meaning, was twice that of *must*, which he found commonly to be subjective. Thus, both weaker strength modals and objective modals allow writers to avoid sounding overly authoritative.

Stance is influenced by the relationship between reader and writer. Where the reader is more powerful than the writer, projecting a forceful authoritative stance is less appropriate (Myers 1989). In addition, the evidence-based nature of science and academic writing in general demands that writers be tentative, taking care not to over-state their authority for making claims. Reader-writer relationship for writers of both published research articles and student assignments mean that overly authoritative language is risky. Research article writers are writing for peers, who expect an appropriate degree of tentativeness about claims made; overly authoritative language risks challenge by the reader. Students are writing for instructors, who again expect students to show tentativeness appropriate to the level of the claim being made, the amount of evidence being provided, and their own novice status. A further factor that influences writer stance is the status of the statements being made.⁵ Those that contain established knowledge need less tentativeness

5. Thanks to a reviewer of this article for this point.

and are less likely to be associated with modals. In contrast, more novel claims need greater tentativeness and are thus more likely to be associated with modals.

2. **Methods**

This study compares three sets of data. Firstly, undergraduate science laboratory reports were compared with research articles, in order to judge the influence of the necessities that arise from experimental work, which are salient in both genres. Secondly, laboratory reports were compared with science essays, in order to judge the influence of register, while keeping reader-writer relationship and discipline the same.

Student writing from the BAWE corpus (British Academic Written English, Nesi & Gardner 2012) was used. The BAWE corpus contains student writing that attained a distinction or merit grade, being thus judged as good writing by the students’ instructors. To investigate modal use in pure and applied science, as well as in biological and physical science, laboratory reports from the disciplines of Biology, Physics and Engineering from the BAWE corpus were included (see Table 1). To limit the variety of English, only reports by British L1-English students were selected. An attempt was made to maximize the number of different writers, but this was limited by the size of the BAWE corpus.

Table 1. Student laboratory reports in the study (sampled from BAWE)

	Number of texts	Number of writers	Number of words
Biology reports	33	17	52,255
Physics reports	149	8	49,179
Engineering reports	26	19	52,243
Total	73	44	153,677

Research articles were included from high impact journals in Biology, Physics and Engineering (see Table 2). An attempt was made to keep the number of words contributed by Biology, Engineering and Physics articles approximately the same. Highly ranked journals were selected using Scimago Journal rankings for 2016.⁶ Selections were limited to empirical articles published between 2013 and 2018. However, I am unable to claim that the research article writers were speakers of British English because researchers are a mobile population, and an English name

6. A full list of the research articles used can be supplied on request.

(as is the case with the first authors of the articles in my data set) is no indication of the variety of English spoken. This is a limitation of this data set.

Table 2. Published research articles in the study

	Number of texts	Number of words
Biology RAs	13	52,202
Physics RAs	15	53,408
Engineering RAs	14	61,806
Total	42	167,416

There were insufficient essays in the BAWE corpus to form an equivalent size data set within the disciplines of Biology, Physics and Engineering. Therefore, to form a data set with an equivalent number of words as the research article and lab report data sets, essays were drawn from nine science disciplines including biological, physical and applied science disciplines (see Table 3). It is possible that this lack of parallelism may skew the findings. However, it is equally likely that the alternative of limiting the essay data to unequal sized data sets from Biology (16,696 words) Engineering (8,380 words) and Physics essays (25,491), would also have had a skewing effect. This is a limitation of this data set.

Table 3. Student essays in the study (sampled from BAWE)

	Number of texts	Number of writers	Number of words
Agriculture essays	9	6	20,302
Biology essays	7	7	16,696
Chemistry essays	6	3	7,494
Computer science essays	6	5	13,403
Engineering essays	5	5	8,380
Food science essays	6	5	10,092
Health science essays	10	9	26,702
Physics essays	12	6	25,491
Psychology essays	12	12	21,467
Total	73	58	150,027

In order to test whether use of modal meaning in science writing is in fact different from modal meaning in more general (non-science) writing, in Section 3.2 I compare my findings to those of Collins (2009a) who investigated modal meaning in the British part of the International Corpus of English (ICE-GB). Findings from only the written part (400,000 words) of ICE-GB (henceforth ICE-GB^w) are

included, because the student writing comes from the BAWE corpus, and is by British students. The ICE corpus is a balanced corpus, the written part of which includes creative, persuasive, instructional, popular, academic, and student writing (from a range of disciplines), as well as letters and reportage (The ICE project 2009).

2.1 Data analysis

Wordsmith Tools (Scott 1996) was used to identify each instance of *must*, *should*, *have to* and *need to* in the data. The same search terms were used as those used by Collins (2009:33). These were *must* (including *mustn't*), *should* (including *shouldn't*), *has to*, *have to*, *had to*, *need to*, *needs to*, *needed to*, and *needing to*. Instances were manually coded as deontic, dynamic or epistemic by considering each instance in context. Instances that were not modals (e.g., *There is a need to centre this on factors*) were omitted from the counts. Similarly, as subjunctive instances of *should* do not imply obligation or necessity (Example 11), these were removed from the analysis.

- (11) This suggested that *should* the two streams become polluted the lower stream would contain a higher diversity than the upper stream.
(Laboratory report biology, BAWE6013h)

To maximise reliability, all the data was independently coded by both the author and a second applied linguist with expertise in modality. The initial rate of similarity was 92.9% (that is, the two coders viewed 61 instances out of a total of 863 instances as belonging to different categories of modality). Differences were discussed, with each coder justifying the category they had assigned. The following is an Example (12):

- (12) To produce the above mistakes illustrate that [sic] infants have grasped the concept that words are divided into morphemes and affixes can alter their meanings. To use these affixes appropriately, they *must* also understand the concepts of plurality and tense. Therefore these mistakes, although non-standard English, are actually intelligent because they illustrate the infant has the ability to apply grammatical rules (Psychology essay, BAWE0190a)

One coder viewed this as epistemic modality, suggesting that the author is advancing the logical argument that if infants can use affixes appropriately, the likelihood is that they do understand the idea of plurality. The other coder initially viewed this as deontic modality in that the grammatical rules apply. After discussion, we agreed that an epistemic reading was the more credible and the instance was coded as epistemic.

In Example (13) one coder read *must* as dynamic (the withdrawal of the herbicide is the circumstance necessitating a more holistic approach) while the other coder's reading was deontic (that it is the view of the researcher that this is what must happen). After discussion we agreed that both meanings are possible. This is a well-recognized phenomenon in discussions of modal meaning. For example, Palmer (1979: 173) notes that although there are categories with "clearly distinct" extremes, there is also indeterminacy between the extremes, with instances that could fit the categories at both extremes. Because both dynamic and deontic meanings are possible, Example (13) is an instance that was eventually coded as indeterminate.

- (13) The withdrawal of a large proportion of herbicides from use in the horticultural sector means that growers *must* implement a more holistic approach to crop management. (Biology essay, BAWE6214d)

In general consensus was reached in most instances, with a remaining 18 instances of disagreement, resulting in inter-coder agreement of 97.9%.

Instances were also manually coded as subjective or objective. Log likelihood (Rayson 2016) was used to calculate whether frequency differences observed between the different sets of data were significant.

3. Quantitative results

In this section, I begin by reporting, in Section 3.1, the quantitative comparison between student laboratory reports, student essays, and published research articles. I then move on, in Section 3.2, to compare the findings concerning these academic and research genres in science disciplines with findings from a general English corpus reported by Collins (2009a).

3.1 Obligation modals in academic and research writing in science

Appendix 1 shows the raw frequencies of *have to*, *must*, *need to*, and *should* in the three genres of academic writing in science: student laboratory reports, student essays, and published research articles. Table 4 shows normalized frequencies (per 10,000 words) of the modal verbs *must* and *should* and the quasi-modals *have to* and *need to*. Table 4 shows that, of the three science genres, student essays have the most frequent use of the modal verbs *must* and *should* and of the quasi-modals *have to* and *need to* while research articles use them most sparingly.

One possible explanation for this difference is that research article authors may avoid representing their work in such absolute and definite terms as is

Table 4. Frequency per 10,000 words of *have to*, *must*, *need to* and *should* in laboratory reports, essays and published research articles and ICE-GB^w

	Laboratory reports	Essays	Research articles
Have to	2.7	4.1	1.1
Must	5.8	9.5	1.8
Need to	3.2	8.1	0.8
Should	5.5	10.0	3.1
Total	17.2	32.7	6.8

implied by *must*, *should*, *have to* and *need to*. Using absolute language is potentially face-threatening to readers and may be perceived as lacking appropriate tentativeness. Another possibility is that discussion of research methods, results and findings in research articles may require different expression of obligation and necessity than is found in genres written for other purposes. This is supported by my discussion below of Table 5 which shows a lower frequency of deontic meaning in the two empirical science genres in this study, research articles (RAs) and laboratory reports, compared to student essays and ICE-GB^w. Thus laboratory report writers are similar to research article writers in avoiding these modal resources, although their avoidance is less marked than that of the research article writers.

In addition to the frequency of the use of each modal, also of interest is the meanings which each of these modals and quasi-modals expresses in the three science genres. Table 5 compares the frequency and the overall proportion of uses that have deontic, epistemic and dynamic meaning. Confirming the observation made above in discussing Table 4, that research article writers avoid using obligation modals, Table 5 shows that the frequency per 10,000 words for the use of the four modals for deontic, epistemic and dynamic meaning is consistently lower in research articles than in either student genre or in ICE-GB^w.

Table 5 shows that in their laboratory reports, students use deontic, epistemic and dynamic meaning about one third of the time respectively. This is rather different from student writing in science essays, where deontic meaning is predominant and epistemic meaning is relatively lower. Deontic meaning in essays is used when citing literature, and as published research is regarded in the light of strong evidence in academic writing, the high frequency and high proportion of deontic meaning in essays is expected.

Table 5 also shows that epistemic *have to* and *need to* are rare in the three science genres. It is well recognized (e.g., Leech, Hundt, Mair, & Smith 2009: 109) that the ‘root’ meaning of modals (i.e., deontic and dynamic meaning) is more literal and less abstract than epistemic meaning. With the rapid growth in the use of these quasi-modals since the 1960s (Leech et al. 2009: 97; Collins 2009b), it

Table 5. Frequency per 10,000 words of deontic, epistemic and dynamic meanings of *have to*, *must*, *need to* and *should* in laboratory reports, essays and published research articles and ICE-GB^w

		Laboratory reports	Essays	Research articles
Deontic	Have to	0.6	1.9	0.6
	Must	1.6	5.0	0.7
	Need to	1.2	4.9	0.4
	Should	1.7	7.7	1.7
	Total	5.1 (30%)	19.5 (61%)	3.4 (49%)
Dynamic	Have to	2.0	2.1	0.4
	Must	2.0	2.2	0.7
	Need to	1.9	3.2	0.5
	Should	0.0	0.0	0.0
	Total	5.9 (35%)	7.5 (24%)	1.6 (23%)
Epistemic	Have to	0.0	0.1	0.1
	Must	2.1	2.1	0.4
	Need to	0.1	0.0	0.0
	Should	3.6	2.1	1.4
	Total	5.8 (34%)	4.3 (14%)	1.9 (28%)
Indeterminate	Have to	0.1	0.1	0.0
	Must	0.1	0.3	0.0
	Need to	0.0	0.1	0.0
	Should	0.2	0.1	0.0
	Total	0.4 (2%)	0.6 (2%)	0.0 (0%)

appears that growth in the use of their more abstract epistemic meanings has not kept pace with growth in dynamic and deontic uses.

Next I move on to a comparison of the three science genres that are the focus of this study and consider deontic, epistemic and dynamic uses of the modals in the three genres. In Table 6, using log likelihood, I compare laboratory reports firstly with research articles, and secondly with essays. Log-likelihood is used to test whether frequencies being compared are significant. Log-likelihood values that show a significant difference are shown in bold in Table 6. Log-likelihood is calculated using raw scores, and the frequencies shown in Table 6 are therefore raw scores. For normalized frequencies, please see Table 5. In the discussion that follows, a p-value of 0.001 is employed in discussing significance.

Table 6 shows that the frequency of use of deontic meaning is not statistically different in laboratory reports and research articles for *have to* and *should*. Differences for deontic *must* and *need to*, although present, have rather low

log-likelihood value (LL), and are not are significant at the $p < 0.001$ level. This suggests that writers of laboratory reports and research articles use these four modals with similar, rather low, frequencies to express meanings representing themselves as an authority, representing the literature as an authority (Example 5) and citing rules and regulations as an authority (Example 6). Table 5 shows the total normed frequency for deontic meanings in laboratory reports to be 5.1 per 10,000 words, and for RAs to be 3.4 per 10,000 words. These frequencies for laboratory reports and research articles show sparing use of deontic modality in these two genres when compared with the frequency of use of deontic modality in essays (19.5 per 10,000 words).

As noted above in the discussion of Table 5, *have to* and *need to* are hardly used epistemically in either genre. However, laboratory reports employ epistemic use of *must* and *should* with statistically far greater frequency than RAs do, as Table 6 shows. Overall, laboratory report writers employ epistemic meanings of obligation modals far more frequently (5.9 per 10,000 words, see Table 5), than RAs do (2.0 per 10,000 words). This means that laboratory report writers use obligation modals for the purpose of arguments based in logical necessity (Example 10) significantly more frequently than research article writers.

The dynamic use of *should* is absent in both genres. But laboratory reports use dynamic *must*, *have to* and *need to* with far greater frequency than RAs do ($p < 0.001$, see Table 6). This means that laboratory reports represent the necessity for doing actions in terms of circumstances (Example 9) or purpose (Example 8) more frequently (normed frequency 6.2 per 10,000 words) than RAs do (1.7 per 10,000 words).

The above discussion shows that the frequency of deontic meaning is similar between laboratory reports and research articles, but that there are large frequency differences for epistemic and dynamic meaning. The opposite is the case when obligation modal use is compared between laboratory reports and essays.

The log-likelihood comparison of laboratory reports and essays in Table 6 shows that student writers use epistemic and dynamic obligation modals with similar frequencies in essays and laboratory reports. The frequencies of dynamic *have to* and dynamic *must* are not significantly different, and differences in frequencies of dynamic *need to* and *should* have rather low log-likelihood value (LL), and are not are significant at the $p < 0.001$ level. That is, when writing laboratory reports, writers represent the necessity for doing actions in terms of circumstances or purpose about as frequently as they do when writing essays (normed frequencies 6.1 per 10,000 words for laboratory reports and 8.7 per 10,000 words for essays).

In both genres the epistemic use of *have to* and *need to* are rare. Epistemic uses of *must* are not significantly different in the two genres; differences in frequencies of epistemic *should* have rather low log-likelihood value (LL), and are

not are significant at the $p < 0.001$ level. Thus it can be concluded that obligation modal resources are used only slightly more frequently for the purpose of logical argument by students writing laboratory reports than by students writing essays.

Table 6. Frequency of *have to*, *must*, *need to* and *should* in laboratory reports compared to RAs, and in laboratory reports compared to student essays

		Laboratory reports	Essay	Research articles	LL Lab reports compared to RAs	LL Lab reports compared to essays
Deontic	Have to	9	28	10	0.0	10.7 ^b
	Must	24	75	12	5.17 ^a	28.82 ^d
	Need to	19	73	6	8.26 ^b	35.14 ^d
	Should	26	116	29	0.01	63.84 ^d
Epistemic	Have to	0	1	1	1.13	1.41
	Must	33	31	7	20.65 ^d	0.02
	Need to	1	0	0	1.47	1.36
	Should	56	32	23	17.19 ^d	6.06 ^a
Dynamic	Have to	31	32	7	18.5 ^d	0.05
	Must	30	33	11	10.85 ^c	0.22
	Need to	29	48	8	14.53 ^c	5.2 ^a
	Should	0	0	0		

a. 5% level; $p < 0.05$; critical value = 3.84

b. 1% level; $p < 0.01$; critical value = 6.63

c. 0.1% level; $p < 0.001$; critical value = 10.83

d. 0.01% level; $p < 0.0001$; critical value = 15.13

The picture is very different, however, for the use of obligation modals with deontic meaning (Table 7). In writing essays, students make heavy use of deontic modality, while students writing laboratory reports do not. In fact, a look at instances of use shows that writers of student essays rely heavily on the literature as the source of necessity, while students writing laboratory reports seldom cite literature. In essays, student writers also use rules and regulations as a source of obligation far more frequently than they do in writing laboratory reports. In both genres, discourse internal sources, such as the writer or the literature, are the source of obligation more frequently than rules and regulations are.

In summary, this section has shown statistical similarities in the frequency of the use of deontic modal meaning between RAs and laboratory reports (the two empirical genres) and statistical similarities in the frequency of the use of epistemic and dynamic modal meanings between laboratory reports and essays (the two student genres).

Table 7. Deontic modality in essays and laboratory reports: Frequency per 10,000 words of *have to*, *must*, *need to* and *should*

	Laboratory reports		Essays	
	Discourse internal source	Rules and regulations	Discourse internal source	Rules and regulations
Have to	0.6	0.0	0.8	1.1
Must	1.0	0.6	3.1	1.9
Need to	1.0	0.2	4.1	0.7
Should	1.6	0.1	5.1	2.6
Total	4.2	0.9	13.1	6.3

3.2 Comparison of the use of obligation modals in science and their use in a general English corpus

In this section I compare my findings, outlined in Section 3.1, with the use of *have to*, *must*, *need to* and *should* in the British part of the International Corpus of English (Collins 2009a). This comparison is important in that it shows the extent to which the use of obligation modals in science is distinct from their use in general English. The comparison illuminates how modal use responds to expression of meanings that are important in science disciplines. It also demonstrates the extent to which the empirical genres (laboratory reports and research articles) show similarities with each other, and the extent to which use in a non-empirical science genre (student essay) is closer to general use in written English.

Table 8 shows the use of *have to*, *must*, *need to* and *should* in the ICE-GB^w (Collins 2009a). Comparison with the frequencies of these modal resources in the science genres in my data (Table 4) shows that the frequency of all four modal auxiliaries in the ICE-GB^w is greater than their use in published science research articles. Log-likelihood calculations showed this difference to be highly significant. Thus by comparison with the frequency of general use of these modals by British writers (in ICE-GB^w), research articles avoid using obligation modals. Similarly, Table 8 shows significantly higher frequency of *must*, *should* and *have to* in ICE-GB^w than in laboratory reports (Table 4). However, *need to* is more frequent in laboratory reports than in ICE-GB^w, although this difference is not significant.

In contrast, the frequency of use of the modals in British student essays (Table 4) is closer to their more general use by British writers as reflected in ICE-GB^w (Table 8). Frequency differences of the modals *must* and *should* are not significant between student essays and the ICE-GB^w. However, writers in ICE-GB^w use *have to* significantly more frequently than writers of essays, while student essays use *need to* significantly more frequently than writers in ICE-GB^w.

Considering the use of the four modal auxiliaries overall, *need to* represents a much higher proportion (18%) in laboratory reports and essays (26%) compared to ICE-GB^w (8%). As an auxiliary that largely carries objective meaning (Collins 2009a: 73–75), *need to* appears to be useful in discussing the exigencies not only of experimental work in laboratory reports, but of other aspects of science in essays.

Also of interest is the meanings which each of these modals and quasi-modals expresses in the three science genres (Table 5) compared with their frequency in the ICE-GB^w (Table 8). Interestingly, more than 70% of uses in ICE-GB^w have deontic meaning, while in the three science genres, the proportion of deontic meaning ranges from 30% in laboratory reports to 49% in research articles to 61% in science essays (Table 5). This suggests that, by comparison with modal usage in general English, science writers do not put themselves forward as the source of authority.

Overall, proportions of the use of deontic, epistemic and dynamic meanings are rather similar in science essays (Table 5) and in ICE-GB^w (Table 8), while both research articles and laboratory reports show much higher proportions of dynamic and epistemic meaning. This suggests that surrounding circumstances and logical reasoning are more important sources of obligation and necessity in empirical science genres than they are in general English.

This section has shown that expression of meaning using obligation modals in the science register are distinctly different from those expressed in a general English corpus. In particular, dynamic and epistemic meaning are prominent in the empirical genres: research articles and laboratory reports. Of the three science genres, student science essays are most similar in the frequency of use of different meanings to the more general corpus, ICE-GB^w. Both of them have higher overall frequencies of obligation modals than the two empirical genres do.

4. Qualitative results: Meanings expressed and functions performed by modals in the three genres

In this section, I discuss examples of deontic, dynamic and epistemic meaning in each of the modals and quasi-modals. This is important for a consideration of stance, because deontic meaning lends itself more than epistemic or dynamic meaning to the inference of authority. I also consider the issue of subjectivity and objectivity in my three sets of data, because subjectivity positions the writer as the authority, making subjective positioning riskier. For each of these four modal resources, I compare my findings from the three academic and research genres in science with their use in a general English corpus.

Table 8. Frequency per 10,000 words of deontic, epistemic and dynamic meanings of *have to*, *must*, *need to* and *should* in the ICE-GB^w

ICE-GB ^w (Collins 2009a)		
Deontic	Have to	6.8
	Must	6.2
	Need to	0.7
	Should	8.3
	Total	22.0(72%)
Dynamic	Have to	3.4
	Must	0.8
	Need to	1.6
	Should	0.0
	Total	5.8 (19%)
Epistemic	Have to	0.1
	Must	1.7
	Need to	0.1
	Should	1.1
	Total	3.0 (10%)
Total	Have to	10.2
	Must	8.6
	Need to	2.5
	Should	9.4
	Total	30.7

4.1 *Must*

Although the predominant meaning of *must* in written English in general is deontic necessity (71% of instances in ICE-GB^w; Collins 2009a: 164), this was not the case in either the laboratory reports (27%) or published research articles (40%). In the essays, however, 52% of instances of *must* expressed deontic meaning.

In addition to its relatively low usage the three science genres in this study, deontic *must* was largely objective in these science genres. Instances of deontic *must* with a rules and regulations source (see Example 6) were almost entirely objective, and where the source was discourse internal, deontic *must* was also more frequently objective (Example 14) than subjective (Example 15). The phrase *it must be noted* (Example 14) was frequent in all three of my sets of data in the science register, and can be considered close to formulaic in academic writing in general.

- (14) It *must* be noted that there is a definite variability with these sets though.
(Laboratory report engineering, BAWEO347h)
- (15) I don't think this is what a professional engineer is, although I do think that a professional engineer *must* work in this "professional manner"
(Essay engineering, BAWEO354f)

In my data, epistemic *must* is very largely objective (see Example 16). This is distinctly different from the findings of Verstraete (2001) using ICE-GB, who, as discussed above, argues that epistemic modality is always subjective. Collins (2009a), in contrast, also using ICE-GB, argues that objective epistemic modality is possible, but less frequent than subjective epistemic modality.

- (16) In the solvent-interaction model the analyte molecule is partitioned between the mobile phase and the layer of adsorbed solvent molecules. The solvent-competition model has the analyte molecules competing with the strong solvent molecules for active sites in the stationary phase. However, both models assume that the interactions between a certain analyte and the stationary phase remain constant. Therefore, it *must* be concluded that retention is determined by the composition of the mobile phase for any particular stationary phase. If both models have the same outcome it must be presumed that they are equivalent to another. High Performance Liquid Chromatography Fundamental Principles and Practice, ed. W.J. Lough, I.W. Wainer, Blackie Academic & Professional, Glasgow 1995
(Essay Chemistry, BAWEO388d)

The textbook cited at the end of Example (16), or its author, could be argued to have a relationship of commitment towards the propositional content. However, both the situating of the textbook reference at the end of the paragraph and the passive *it must be concluded* are strategies used by the writer to make this impersonal and objective.

Another way in which use of obligation modals the science genres in my data are distinguished from general English usage, is the high frequency of dynamic meaning. Collins found dynamic *must* to be a minor category, but, as noted above in discussion of Table 5, this is not the case in my data. Although there is a lower frequency of dynamic *must* than deontic *must* in essays, in laboratory reports dynamic *must* predominates, and in RAs dynamic and deontic *must* are equally frequent. In Example (17), the circumstances surrounding the event are the source responsible for the necessity, while in Example (8) above, a condition/purpose is the responsible source:

- (17) The scattering data demonstrate the elliptical patterns, which vary qualitatively by sample and thus *must* be measured directly
(RA physics, P9)

Overall the above discussion indicates that deontic meaning is not the predominant meaning for *must* as it is in the more general written corpus, the ICE-GB^w. In experimental science genres, such as laboratory reports and research articles, both epistemic and dynamic *must* are at least as frequent as deontic *must*. This discussion also suggests that in the science register, *must* is very largely objective, with some subjective instances of epistemic *must* in essays and a few instances of subjective deontic *must* in all three genres. Thus, not unexpectedly, the academic science register is weighted towards the objective by comparison with ICE-GB^w. In addition, deontic meanings are less important than in ICE-GB^w and epistemic meanings, which facilitate logical argument are more frequent, as well as dynamic meaning where circumstances and purpose are responsible for the necessity expressed. Both of these trends, weighting towards objectivity and the relative lack of importance of deontic meanings, contribute to lessening writer authority and bolstering a stance of circumstantial and logical necessity.

4.2 *Should*

As discussed in Section 3.1, deontic *should* was a relatively less prominent meaning in science research articles (56%) and laboratory reports (31%), than it was in either science student essays (77%) or the more general ICE-GB^w (88%) (Collins 2009a: 164). Deontic *should* in my data, like deontic *must*, was more likely to have a discourse internal source (see Example 4) than a rules and regulations source. In fact, in the research articles in my data there were no instances of deontic *should* with a rules and regulations source and very few in the laboratory reports. However, the instances of deontic *should* in the essays included a sizable minority of instances with a rules and regulations source (see Example 18).

- (18) Similarly, good agricultural practice dictates that manure *should* not [be] spread when land is waterlogged, frozen or snow covered.
(Essay agriculture, BAWE6036d)

In my data, deontic *should*, like deontic *must*, is largely objective, as in Example (18), with a small number of subjective instances in the essays only (see Example 4). This contrasts with the use of deontic *should* in ICE-GB^w, where most examples of deontic *should* quoted are subjective Collins (2009a: 46).

Although the frequency of epistemic *should* in the essays in my data is fairly low (21%), a high proportion (66%) of instances of modal *should* in the laboratory reports and research articles (44%) are epistemic. Almost all epistemic instances in my data are objective (see Example 19) with very few subjective instances (20).

In contrast, very few (12%) of modal instances of *should* in ICE-GB^w are epistemic (Collins 2009a: 164).

- (19) This study design also has the advantage of being focused on a relatively recent time period, so *should* reveal the patterns, if any (RA biology, B8)
- (20) I will question two skiers to discover what they know; nanotechnology is important to the skiing community for the aforementioned reasons and therefore they *should* have some knowledge of this topic.
(Essay physics, BAWE6132d)

Collins found no examples of dynamic modality with *should*. He says that “even in those instances where *should* expresses the desirability of an action deriving not from the speaker, or from some moral or legal consideration, but merely from circumstantial expediency, we understand the action to be recommended by the speaker or by some external body representing the deontic source” (Collins 2009a: 44). He gives the following Example (21):

- (21) You may need to grip down and adjust the ball position for some shots but the basics of the swing *should* be the same. (ICE-AUS)

Similarly, in my data there were instances of *should* where necessity appeared to arise from circumstances or a purpose surrounding the activity. However, I accepted Collins’s (2009a) argument that despite the circumstances being put forward to recommend the action, the reader does nevertheless read such examples as being recommended by the speaker and these cases (which were low in number), I identified as deontic (see Examples 22 and 23).

- (22) Semi-aquatic snakes are often kept in terrariums with large water bowls and allowed to bathe for as long as they wish. However excessive soaking can lead to blister disease so access *should* be restricted only to times when they are feeding.
(Essay biology, BAWE6011h)
- (23) This may be deemed a slow release fertilizer, with this conversion occurring over a wider time period than largely nitrate based fertilizers, and in order to reduce nitrate leaching, *should* therefore not be applied later in the growing season.
(Essay agriculture, BAWE6036d)

In summary, the prominence of epistemic *should* in the laboratory reports and research articles in my data and the low incidence of deontic *should* indicates that *should* is used in the science register in expressing logical necessity aiding in logical argument (epistemic meaning) rather than in expressing meanings concerned with human authority or rules and regulations (deontic meaning). The prominence of objective *should* in my data, also a difference from the more general ICE-

GB^w corpus, is also in line with the overall tendency of science writing to describe nature from an impersonal and objective perspective.

4.3 *Have to*

Have to is half as frequent as *must* in laboratory reports, essays and RAs, despite being as frequent as *must* in the ICE-GB^w. This could be because *have to* has recently grown in frequency in general (Collins 2009b), and is therefore perhaps less formal, making it less appropriate in formal academic writing.

Deontic *have to* was a minor category in my data, particularly in laboratory reports. However, as in Collins (2009a), deontic *have to* in my data was largely objective (Example 24) with very few subjective instances (Example 25). In contrast, deontic meanings of *have to* were found in 66% of instances in ICE-GB^w (Collins 2009a: 167).

- (24) Suitable control strategies will also *have to* be developed, although this will require detailed knowledge regarding the distribution, host range and ecology of the newly recognised pathogens. (RA biology, B11)
- (25) The theory of strings is just one step further towards a complete unified model of physics, but until we find it, we will just *have to* be content with individual theories, describing different parts of the universe. (Essay physics, BAWE6097d)

Dynamic *have to* was more prominent than deontic *have to* in my data, particularly in the laboratory reports. Example (9) is an instance where the surrounding circumstances necessitate the action. In Example (26) the activity in the modal clause (moving the slider manually) is necessary for the purpose (plotting the points) to be actualized.

- (26) To plot the points on the graph, the slider *had to* be moved manually. (Laboratory report engineering, BAWE0249i)

Epistemic *have to* is rare in Collins's data (2009a: 63), and Depraetere and Verhulst (2008) also report that epistemic *have to* was rare in their study using ICE-GB^w. Similarly, epistemic *have to* is almost absent from my data. In (27), the writer explains a biochemical process, putting forward a logical argument (using *thus* and *therefore* to track the logical reasoning) about the reactions that are likely to happen during this process.

- (27) Reduced plastocyanin no longer becomes a limiting factor for PSI in the process of producing reduced ferredoxin which is utilised in the conversion of NADP⁺ to NADPH. The number of ATP molecules synthesised per oxygen atom equivalent evolved will decrease i.e. the P/O value will decrease. Thus

non-cyclic phosphorylation would be insufficient to provide sufficient ATP per molecule of NADPH to satisfy the demands of the Calvin cycle. Cyclic phosphorylation would therefore *have to* occur to produce enough ATP to cover the deficit....
(Laboratory report biology, BAWEO265a)

Overall, *have to*, like *must*, was more likely to express dynamic meaning than the deontic meaning that was prominent in Collins's data. This reflects the purpose of empirical science in explaining the circumstances, purposes and conditions surrounding experimental work. As in ICE-GB^w, *have to* was largely objective, which is not unexpected in science writing.

4.4 *Need to*

In all three of my data sets the proportion of *need to* is higher than in ICE-GB^w (Collins 2009a). Collins (2009b: 289) characterizes deontic *need to* as weaker in strength than *have to* or *must*, and this relative weakness of *need to* may be a reason for its higher incidence in academic science text, in which expressing strong authoritative stance is risky.

Interestingly, given the importance of dynamic meaning in the science genres in my study, *need to* is the only one of the four modals to be more frequent in laboratory reports and essays than in ICE-GB^w. This higher frequency the science register may be accounted for by its objective tendency in which circumstances rather than human intervention are likely to be responsible, as well as by its relatively weak strength.

Dynamic *need to*, the more common meaning in the laboratory reports in my data, expresses meanings concerned with the circumstances surrounding the necessity (Example 28) as well as purpose/condition (29):

- (28) DDE causes the eggshell to become thinner and weaker and if DDE gets into the yoke then the chick does not develop properly. There only *needs to* be between a 16 and 18% thinning in the shell from the normal shell thickness for the population of these two birds to start declining.

(Laboratory report biology, BAWE 6013c)

- (29) To balance the bridge we *need to* set the output voltage to zero.

(Laboratory report engineering, BAWEO243a)

Deontic *need to* in my data almost always has a discourse internal human as source (see Example 5), rather than rules and regulations. Objective deontic *need to* is typical in my data (see Example 30), although there are some subjective instances, especially in the essays (Example 31).

- (30) For Cf [equation (12)], two unknowns *need to* be found.
(Laboratory report engineering, BAWE0023d)
- (31) Perhaps the achievement of equity is coming closer but we *need to* accept it
will be another few years in the making. (Essay health, BAWE3034c)

As in Collins's study, epistemic *need to* was rare in my data.

Overall, *need to* was more frequent in my data than in ICE-GB^w, which, as I argue above, may be because it is weighted towards dynamic meaning and towards objective meaning, both of which predominate in the three science genres in my study. Its relative weakness may also make it a less risky choice than a strong modal like *must*.

5. Conclusion

As discussed in the introduction to this article, previous studies have shown variation in modal meaning between spoken and written registers and between different disciplines. However, no studies have investigated register variation within a discipline. This study of academic science writing shows a clear distinction between the three science genres on the one hand and a general written corpus, the ICE-GB^w, on the other. Secondly the study shows distinct variation in modal use between the three science genres.

One similarity between the three science genres and difference from ICE-GB^w is the predominance of objective meaning. This is in line with the tendency in academic writing (particularly in science) to express meaning from an objective perspective. This objective perspective is strengthened by the high frequency of dynamic meaning in the science genres in the study in comparison with the predominance of deontic meanings in ICE-GB^w. This suggests the source of necessity in science writing as being circumstances surrounding an event rather than humans or rules.

A second similarity between the three science genres was the high frequency of epistemic meaning in comparison with ICE-GB^w. This suggests that science writers seek to share with readers their judgements of likelihood of an action or event and the evidence on which this judgement is based. The study also shows a high proportion of objective epistemic meaning, in contrast to Verstraete's (2001) claim that epistemic meaning is invariably subjective. The finding also contrasts with Collins's (2009a) finding that epistemic meaning was largely subjective in ICE-GB^w. This does not, however, show inconsistency with Collins's findings, but rather is an important indication of how meaning is differently used in different

registers. The importance of objectivity in science results in a shift to objective meaning in a meaning category that is largely subjective in more general usage.

As deontic meanings are the more 'authoritative' meanings, whose source is either the writer or other human authority or rules and regulations, it seems likely that deontic obligation meanings are the potentially more face-threatening meanings compared to epistemic and dynamic meanings. In epistemic meanings the writer puts forward a judgement based on logical necessity and shares with the reader their basis for reaching a particular conclusion. In dynamic meanings, surrounding circumstances rather than a human or legal authority necessitate an action. In neither epistemic nor dynamic meanings is the writer setting themselves up as an authority. I suggest this as one factor in their higher frequency in the three science genres in my data.

Another factor contributing to the higher frequency of epistemic and dynamic meanings in comparison with the more general ICE-GB^w corpus is the importance in all three genres of logical argument based on evidence (in which epistemic meaning is useful) and the importance of the conditions and circumstances that accompany natural phenomena (in expression of which dynamic meaning is useful).

This study also shows variation in the use of these modal verbs within different genres of the scientific register, consequent both upon reader-writer relationship (laboratory report compared to research articles) and also upon purpose of writing (discussing/describing/explaining knowledge based on sources in an essay compared to discussing/explaining experimental findings in a laboratory report). The results of the comparison between the genres confirm the hypothesis outlined in the introduction concerning similarities firstly between experimental genres (RAs and laboratory reports), and secondly between the two student genres (laboratory reports and essays).

The two empirical genres, laboratory reports and research articles, use statistically similar low frequencies of deontic meaning. In this way, laboratory reports are similar to research articles. However, laboratory report writers make statistically greater use than research article writers of epistemic meanings suggesting that laboratory report writers use obligation modals for the purpose of arguments based in logical necessity significantly more frequently. Laboratory reports also use statistically more dynamic meanings of obligation modals than research articles do, thus representing the necessity for doing actions in terms of circumstances or purpose more frequently.

In contrast, student writers use epistemic and dynamic obligation modals with similar frequencies in essays and laboratory reports, but they use deontic meaning significantly more frequently in essays than in laboratory reports. Thus it can be concluded that laboratory reports are similar to research articles and

different from essays in their low frequency of deontic meaning. This supports my hypothesis that modal meaning is important in reporting on the exigencies of empirical science, where circumstantial and logical reasons for events are important. However, laboratory reports are similar to essays in the high frequency of dynamic and epistemic meanings expressed in comparison with research articles. This can be speculated to stem from the need to demonstrate to the readers, the students' instructors, the students' understanding of and reasoning about the circumstances surrounding the events expressed. Writer stance is influenced by both the reader (fellow researchers in RAs compared to the instructor in essays and laboratory reports) and the writer's purpose (explaining empirical work in RAs and laboratory reports compared to explaining scientific ideas in essays).

Of the three genres, student essays are the most similar to ICE-GB^w in their use and frequency of modals. One major difference is that objective meaning predominates in student essays, rather than subjective meaning which predominates in ICE-GB^w.

Funding

Research funded by ESRC (RES-000-23-0800).

Acknowledgements

Part of the data in this study come from the British Academic Written English (BAWE) corpus, which was developed at the Universities of Warwick, Reading and Oxford Brookes under the directorship of Hilary Nesi and Sheena Gardner (formerly of the Centre for Applied Linguistics [previously called CELTE, Warwick], Paul Thompson (Department of Applied Linguistics, Reading) and Paul Wickens (Westminster Institute of Education, Oxford Brookes).

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Appendix

Raw frequencies of *have to*, *must*, *need to*, and *should*, in laboratory reports, essays, and research articles

		Laboratory reports	Essays	Research articles
Deontic	Have to	9	28	10
	Must	24	75	12
	Need to	19	73	6
	Should	26	116	29
Dynamic	Have to	31	32	7
	Must	30	33	11
	Need to	29	48	8
	Should	0	0	0
Epistemic	Have to	0	1	1
	Must	33	31	7
	Need to	1	0	0
	Should	56	32	23
Indeterminate	Have to	2	1	0
	Must	2	4	0
	Need to	0	1	0
	Should	3	2	0
Total	Have to	42	62	18
	Must	89	143	30
	Need to	49	122	14
	Should	85	150	52
Words in data set		153,677	150,027	167,416

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