Articles

Metaphor Comprehension and Engineering Texts: Implications for English for Academic Purpose (EAP) and First-year University Student Success

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One of the challenges that students face during the transition from high school to university is mastering discipline-specific academic expectations and norms. From a language perspective, they may encounter new academic and disciplinary vocabulary, some of which will be metaphoric in nature. However, some students whose first language is not English may struggle, as metaphoric competence is not often a consideration in ESL/EAP classrooms (Littlemore & Low, 2006). Among the supports that postsecondary institutions have implemented to improve students' chances of success are diagnostic and post-entry language assessment (Read, 2016). This mixed methods study investigated the comprehension of metaphoric language in first-year engineering reading materials using diagnostic assessment. First, a corpus of first-year engineering texts was qualitatively explored, finding personification and family/relationship metaphors. Subsequently, a metaphor comprehension test was designed using content from the corpus and administered as a reading task in an existing diagnostic assessment for first-year engineering students. Descriptive statistics, correlations, and t-test analysis of the responses revealed that English first-language (L1) students outperformed English second/additional (L2) language students. Further, those who performed poorly on the diagnostic assessment tended to also struggle with the metaphor comprehension task. Implications are discussed for EAP and first-year university classrooms.

Un des défis auxquels les étudiants font face lors de la transition entre l'école secondaire et l'université est la maîtrise des attentes et des normes universitaires propres à chaque discipline. Du point de vue de la langue, il se peut qu'ils rencontrent du vocabulaire nouveau lié à l'université et à une discipline, dont une partie sera de nature métaphorique. Cependant, certains étudiants, dont la première langue n'est pas l'anglais, peuvent éprouver des difficultés, puisque la compétence métaphorique n'est pas souvent prise en considération dans les cours d'ALS/EAP (cours d'anglais académique) (Littlemore & Low, 2006). Parmi les soutiens que les institutions postsecondaires ont mis en place pour améliorer les chances de réussite des étudiants, on trouve des évaluations langagières dia-

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gnostiques après l'admission à l'université (Read, 2016). Cette étude, à l'aide de diverses méthodes, a enquêté sur la compréhension du langage métaphorique dans les ouvrages de lecture de première année d'ingénierie en utilisant une évaluation diagnostique. Tout d'abord, on a évalué la qualité d'un corpus de textes d'ingénierie de première année pour y trouver des métaphores liées à la personnification, à la famille et aux relations. Par la suite, on a conçu un test de compréhension des métaphores tirées du corpus et on l'a administré comme une tâche de lecture dans un test d'évaluation diagnostique déjà existant pour les étudiants en première année d'ingénierie. Des statistiques descriptives, des corrélations et une analyse test-t des réponses ont révélé que les étudiants dont la première langue était l'anglais (L1) avaient mieux réussi que les étudiants dont l'anglais était la seconde langue ou la langue supplémentaire (L2). De plus, ceux qui n'avaient pas obtenu de bons résultats au test diagnostique, avaient aussi eu des difficultés dans la partie de compréhension des métaphores. On discute des implications pour les cours d'anglais académique et les cours de première année d'université.

Keywords: metaphor comprehension; diagnostic assessment; EAP; transition to university; first-year engineering

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Canadian postsecondary classrooms have become culturally and linguistically diverse due to internationalization efforts and decades of immigration (Anderson, 2015; Statistics Canada, 2017). This is especially true in STEM (science, technology, engineering, math) programs. According to data from the Association of Universities and Colleges of Canada (2011), the most popular programs of study for international students are business and engineering, and international students are more likely to enroll in business, engineering, or math programs than domestic students. The transition from high school into university is a difficult one, especially for students whose first language is not English (e.g., Cheng & Fox, 2008; Fox et al., 2014; Keefe & Shi, 2017; Roessingh & Douglas, 2012; Tweedie & Kim, 2015). These students may be navigating new forms of language and culture in multiple senses. Some may be living in an English-speaking country and away from home and support systems for the first time. Tertiary differs greatly from secondary education, and even though students may begin to learn some discourse and cultural norms of certain subject areas in high school, they will encounter new norms and expectations in university. As such, the concept of culture in this paper takes a multifaceted, macro and micro approach to include the sociogeographic sense, within academia broadly (high school versus university academic culture), and more narrowly at the disciplinary level.

The Canadian postsecondary landscape is linguistically complex. In addition to students whose first language is English or French, there are students whose first language may be an Indigenous language, international students whose first language may or may not be English, and immigrant students who may have some schooling in Canada, but do not speak English as their first language and/or speak another language at home. This last group of students is sometimes referred to in the literature as "Generation 1.5" and research has revealed that they may encounter academic difficulties due to English language proficiency issues (e.g., Crossman & Pinchbeck, 2012; Garnett, 2012; Kim & Duff, 2012). Given this linguistic diversity, dichotomizing students into only two linguistic groups like *native* and *non-native* speaking is problematic. However, a distinction of some sort was necessary in this study. As such, the terms *English L1* and *English L2* speakers/students are used throughout this paper to differentiate students who spoke English or a language other than English as their first language. English may be a student's third, fourth, etc. language, so the term *English L2* is meant to incorporate this understanding.

Language comprehension and use are among the many impacts on student success (e.g., Cheng & Fox, 2008; Fox & Artemeva, 2017; Fox, Haggerty & Artemeva, 2016; Van Viegen & Russell, 2019). For example, students must master the subject-specific academic norms and vocabulary of their disciplines, which may differ from high school to college or university (e.g., Crossman, 2018; Green & Lambert, 2018). Students must also be able to understand the English metaphoric language used to explain difficult or complicated concepts. Metaphoric competence is a difficult concept to define (e.g., O'Reilly & Marsden, 2020); however, Littlemore's (2001a) definition provided some insights: "the ability to acquire, produce, and interpret metaphors in the target language" (p. 459). Existing literature demonstrates the benefits for English L2 students of developing metaphoric competence (e.g., Hoang, 2014; Littlemore, 2001a; Low, 1988) and the difficulties they have in recognizing, correctly interpreting, and producing metaphors in English (e.g., Danesi, 1995; Gunderson et al., 1988; Kathpalia & Carmel, 2011; Littlemore, 2001b). However, with a few notable exceptions (e.g., Duff et al., 2015; Ferreira, 2020; Ferreira & Zappa-Hollman, 2019), metaphor comprehension is often conspicuously absent from English as a second/additional language (ESL/EAL) and EAP curricula (Littlemore & Low, 2006). This small-scale, mixed methods study aims to shed light on the impact of metaphoric content in engineering reading material encountered by first-year university students.

What is Metaphor?

Lakoff and Johnson (1980) described metaphor as "understanding and experiencing one kind of thing in terms of another" (p. 5). Using metaphoric words and phrases allows speakers of a language to think about, talk about, and write about things or concepts in ways that expand literal meaning and deepen comprehension. A common metaphor, for example, in Western society is to refer to the abstract concept of time as a physical object with value: time is *spent*, *passed*, and *lost*. However, the literal conception of time does not have physical properties. The words and expressions used demonstrate how members of a linguistic and cultural community think about and understand the concept of time. Speakers do not typically think about this consciously in their first language. Lakoff and Johnson suggested that metaphor is "…pervasive in everyday life, not just in language but in thought and action" (p. 3). Metaphors can be novel or spontaneous, and newly created, or conventional and in regular use. Shutova et al. (2013) defined novel metaphors as those that are made up for creative effect, and conventional metaphors as having become entrenched in everyday speech.

There are different types or categorizations of metaphor. Grammatical metaphor consists of grammatical forms that have more than one meaning. This approach has strong ties to Halliday's (1985) systemic functional linguistics. Another type of metaphor—the focus of this study—is conceptual metaphor or the "abstract underlying relationship(s)" represented between two entities (Littlemore & Low, 2006, p. 270). Littlemore and Low explained how conceptual metaphors are expressed through an A IS/ARE B structure, where A represents a source domain and B a target domain (p. 270). For example, in the THEORIES ARE STRUCTURES metaphor, *theories* are the target domain and *structures* the source domain, and the metaphor manifests in statements like: "that is a strong *foundation* for your theory," and "the theory needs more *support*" (p. 270). In the first statement, the concept of theory, the target domain, is conceptualized as a structure with a foundation, like a building, and this is the source domain or how the target domain is realized metaphorically. In the second statement, theory is envisioned as a structure needing to be strengthened. Steen et al. (2010) investigated metaphoric language in the British National Corpus (BNC) and found that 99% of metaphors in common use are conventional and 98% manifest as conceptual metaphors, where meaning must be indirectly drawn out from a word's use in context (see also Steen, 2011).

Contemporary Metaphor Theory

The theoretical lens that guided this research is contemporary metaphor theory (CMT) (Steen, 2008, 2011), which has its roots in Lakoff and Johnson's (1980) conceptual metaphor theory. This cognitive-based theory suggests that the human conceptual system is metaphoric. In other words, the way humans think about certain things is metaphoric in nature, and metaphors help them relate to the world. These thought processes manifest in language use, "since communication is based on the same conceptual system that we use in thinking and acting" (p. 3). An important aspect of conceptual metaphor theory that has implications for English language classrooms is the cultural nature of metaphor. Lakoff and Johnson posited that "the most fundamental values in a culture will be coherent with the metaphorical structure of the most fundamental concepts in the culture" (p. 22). As such, English L2 students may grasp metaphor in their first language, but the metaphors they encounter in English may not exist in their language and culture or have different cultural referents.

Using the TIME IS MONEY metaphor as an example, Lakoff and Johnson explained how this English metaphor stems from the development of the concept of work in Western society and customs of paying for work and other things in increments of time: wages per hour, hotel rooms by night, telephone charges by the minute, and so on (p. 8). They noted that these practices are relatively recent in relation to human history and cannot be assumed in all cultures and languages. Metaphors relating to direction and orientation of subjects and objects may also be confusing for students whose culture has different conceptions. For example, "in some cultures the future is in front of us, whereas in others it is in the back" (Lakoff & Johnson, p. 14). In another example provided by Lakoff and Johnson, Western culture conceives of things in polarized up-down orientations, whereas other cultures favour a balanced or more middle-of-the-road approach.

Lakoff (1993) worked to modernize conceptual metaphor theory, and Steen (2008, 2011) in turn, refreshed Lakoff's ideas and gave the theory its current name. Steen (2008) introduced a three-dimensional model that considered metaphor not just in thought and language (i.e., conceptual and linguistic manifestations), but also from the perspective of communicative function. He carefully differentiated the three dimensions (language, thought, communication) and the existing approaches (semiotic and psychological), and added a social approach that recognized metaphor use in shared representations in social interactions (Steen, 2011). He noted that this new framework allowed for the distinctions of deliberate and non-deliberate use of conventional and novel metaphors in similes (signalled with like or as) and metaphoric expressions (non-signalled).

The Pervasiveness of Metaphor in English Academic Discourse

One might be surprised at the volume of metaphor in English language, and more specifically, in academic discourse. Steen et al. (2010) found in a sampling of the BNC that one in every seven to eight lexical units were metaphoric. Steen et al. also investigated the differences in how metaphoric language occurred within four different genres of the BNC: news, fiction, academic, and conversation. Although the tendency may be to assume that the fiction genre would contain the greatest concentration of metaphor, it was in fact the academic genre at just under 20%. Dorst (2015) further examined metaphors in British novels, news texts, academic discourse, and face-to-face speech, expecting to find the highest concentration of metaphors in the literary genre. However, she again found that the academic texts contained the most metaphors, while the literary genre placed a distant third.

Metaphoric content exists in all academic disciplines, including STEM subjects. Semino (2008) explained that although within a traditional view of the discipline of science, "metaphor tends to be regarded as at best irrelevant and at worst detrimental . . . this view has been progressively displaced by the recognition that the use of metaphor in science is both pervasive and essential" (p. 131). In his book about metaphor in science, Brown (2003) reasoned that while the role of metaphor in science is still debated within the discipline, much of what scientists do is governed by metaphoric reasoning. English (1997) contributed to the discussion on mathematical reasoning with her edited collection, citing the importance of analogy, metaphor, and imagery.

Why is Metaphoric Competence Important?

The benefits of developing metaphoric competence are well-documented in the literature. Low (1988) suggested that it enables students to learn to create, manipulate, and understand metaphors that are contextually and socially appropriate. Littlemore (2001a) further argued that overall communicative competence can be improved as communication strategies such as lexical innovation and paraphrasing are developed. MacLennan (1994) suggested that because of metaphor's central role in language structure, the way in which it facilitates concept development, and the manner in which it cognitively links physical objects and abstract concepts, it can help students learn grammar and vocabulary. From the STEM perspective, Sanborn Scott (2000) in his article about math equations explained that "metaphors are useful because their encapsulation gives a toehold for understanding" (p. 1021). Finally, Whaley (2010) asserted that "metaphors are essential for teaching and learning novel, complex, or abstract notions" and serve in explanatory, constitutive, and communicative capacities in science (p. 479).

Metaphor Comprehension Studies

Metaphoric competence is something that those learning ESL/EAL struggle with. When encountering unknown vocabulary, learners (especially those with lower proficiency levels) sometimes default to literal interpretations of words, a phenomenon that Danesi (1995) referred to as "textbook literalness" (p. 453). This, he reasoned, may lead to L2 discourse sounding or appearing unnatural to L1 speakers. There have been studies conducted on metaphor comprehension in reading, albeit little in the postsecondary—or Canadian—context. Roessingh and Kover (2003) investigated curricular interventions and ESL supports in a series of high school English literacy courses that were required for university entrance in Alberta, Canada, including Grade

12 English. They found that although English L2 students were linguistically and academically competent, their achievement on standardized provincial exams did not always reflect their abilities. They suggested that this may be due to the "demands of the dominant culture" or the "internalized ways of knowing and understanding the world that are represented by the way of metaphor not being accessible" (p. 17). These findings were consistent with Gunderson et al.'s (1988) study comparing adult ESL learners with English L1 university students in their understanding of newspaper articles. They discovered that the university students outperformed the adult L2 speakers in general understanding of the articles, as well as in correctly interpreting the figurative content. Boers (2000) probed metaphoric awareness raising and found that some students' reading comprehension and retention of figurative vocabulary in economic news reports improved with explicit attention to the source domain or origin of figurative expressions. Finally, although not in the postsecondary context, Meissner (2010) examined metaphor in English textbooks with Norwegian Grade 8 students. She discovered comprehension issues when the metaphors in the textbooks were different than Norwegian equivalents or were complicated in structure.

Diagnostic and Post-entry Language Assessment (PELA)

Tertiary institutions have introduced an expanding array of supports to assist students in transitioning into postsecondary education and succeeding in their studies. One strategy increasingly drawn upon is diagnostic and post-entry language assessment (PELA) (e.g., Alderson, 2005; Fox & Artemeva, 2017; Fox, Haggerty, & Artemeva, 2016; Fox, von Randow, & Volkov, 2016; Read, 2008, 2016). Diagnostic assessment and PELA processes aim to identify and address students' academic and/or linguistic strengths and weaknesses early in their studies and offer pedagogic interventions to better facilitate their transition into postsecondary education and success during their studies. Original diagnostic and PELA efforts were generic in nature, with the goal of gauging students' understanding of academic language regardless of their first language or program of study (Fox, von Randow, & Volkov, 2016; Read, 2008). However, Fox and Artemeva (2017) pointed out that while many students tend to take more general or foundational courses in their first year and discipline-specific courses in subsequent years, in professional programs like engineering, students take more discipline-specific courses upon entry.

Examples of discipline-specific diagnostic assessments have emerged in the literature. Smaill et al. (2012) administered a diagnostic test to gauge the preparedness of first-year electrical engineering students at the University of Auckland in New Zealand. They found problems with conceptual models and applications of fundamental rules, which they could address before moving on to more complicated topics. At McMaster University in Canada, Kajander and Lovric (2005) developed the "Mathematics Background Questionnaire" that was administered during the first week of classes to students enrolled in a first-year calculus course. The assessment included a questionnaire that elicited demographic and narrative information about students' experiences with high school mathematics and their expectations for university math, as well as a mathematics test. The assessment revealed weaknesses with certain basic computations, mathematical reasoning, and expressing mathematical concepts in narrative form. The pedagogic intervention in this case was two-fold: the redesign of the first-year calculus course and creation of a "Mathematics Review Manual" that was provided to all new students entering programs in science, engineering, and arts and science.

Study Aims and Research Questions

This study aims to provide empirical evidence in the Canadian postsecondary context, of metaphoric language in university STEM reading material (primarily textbooks) and examine any impacts on students' comprehension of the metaphoric content in order to facilitate a smoother transition into university and success during postsecondary studies. Inspired by metaphor research in academic listening (Littlemore, 2001b; Littlemore et al., 2011), this study probes metaphor in reading since Littlemore and Low (2006) suggested that "foreign language learners probably need to understand metaphor more often than they need to produce it" (p. 46). Three research questions guided this study: (1) To what extent are metaphors prevalent in reading material used in first-year engineering courses? (2) Does metaphor comprehension impact reading comprehension of engineering texts? (3) Does a student's first language impact comprehension of metaphors in English? These questions were explored using an existing diagnostic assessment administered to all first-year engineering students at a mid-sized, comprehensive, Canadian university.

The diagnostic assessment employed in this research has been an ongoing, decade-long, interdisciplinary, and collaborative undertaking between applied linguistics and engineering at a Canadian university (Fox & Artemeva, 2017; Fox, von Randow, & Volkov, 2016). A language testing and assessment researcher began working with the Faculty of Engineering in 2009. In the earliest iterations of the diagnostic assessment procedure, tasks from the University of Auckland's DELNA assessment, which measures general academic language competence (a generic PELA) (Read, 2013), were leased and administered to new, first-year engineering students online before the beginning of classes. Based on ongoing, longitudinal research in a multistage evaluation study (Fox, Haggerty, & Artemeva, 2016) the diagnostic procedure was adapted for more discipline-specific use and administered in class at the beginning of the first term of study. At the time this research was conducted, the assessment included an integrated graph interpretation writing task based on an in-class lecture, an academic vocabulary task, language intuition (clozeelide reading), and math tasks. To facilitate the pedagogic intervention part of the procedure, a help centre dedicated to first-year engineering students was opened. It was staffed by upper year undergraduate engineering students (to support understanding of engineering content), and graduate students in applied linguistics with backgrounds in ESL, writing, and teaching (to support communication of that content across engineering assignments) (Fox, Haggerty, & Artemeva, 2016).

Method

Method Overview

This study used a two-phase mixed methods sequential exploratory design (Plano Clark & Creswell, 2008). In the first phase, corpus data was explored and analyzed qualitatively to get a sense of the metaphoric content. The findings from Phase 1 informed the second phase, where a metaphor comprehension test task was designed and administered. The test task results were analyzed quantitatively and compared with other test tasks on the diagnostic assessment. The small sample size (number of students who wrote the diagnostic assessment and completed the metaphor test task) contributes to the exploratory nature of the research.

Participants

There were no participants in Phase 1 of the study. The participants involved in Phase 2 were 42 new engineering students who began their program in January 2015. This cohort was much smaller than a typical September (fall) cohort, which is when most students start their studies. They ranged in age from 16 to 31, with the majority being 18 or 19. Almost all of the students were male; there were only four female students. This group was also more ethnically and linguistically diverse than a typical fall cohort as some students had just completed EAP courses to meet the language requirement for full admission into their program. Less than half of this group were Canadian citizens and most of the international students had been in Canada one year or less. The most common languages spoken by these students other than English were Arabic and Chinese.

Instruments

There were two instruments used in the study. In Phase 1, an existing corpus (804,739 words) that had been built at the institution where the research was conducted with materials used at that time in first-year engineering courses (Wood & Appel, 2012) was explored for metaphoric content. The corpus was divided by its creators into five subtopics as follows, in the order of largest to smallest proportion: physics, chemistry, calculus, problem solving and computers (shortened to computers), and engineering mechanics (shortened to mechanics). The texts within the corpus represented both required and recommended readings from first-year engineering classes, without "instructional language (i.e., end of chapter problem sets, instructional exercises/activities etc.)," which was removed (Wood & Appel, 2014, p. 4). In Phase 2, the instrument was the metaphor comprehension test task that was designed based on Phase 1 findings. Labelled in the diagnostic assessment as *reading for detail*, it comprised 10 underlined metaphoric words and phrases embedded in three small paragraphs of text taken from the corpus. Students were asked to explain the underlined passages in their own words and in the context of the accompanying text. The complete test task appears in Appendix A and is further explained below.

Procedures and Analysis

Tognini-Bonelli (2001) differentiated between corpus-based and corpus-driven research. Deignan's (2005) simplified interpretation of the latter is investigating what emerges from a corpus without a paradigm or assumptions in mind. Phase 1 of this study can be described as corpus-driven according to this interpretation. The corpus was not analyzed quantitatively in the traditional sense to account for or define every occurrence of metaphor. Rather, it was explored qualitatively to get a sense of the distribution of metaphor in each of the subtopic areas of the corpus (though some quantification occurred here), as well as the nature of the metaphoric language (i.e., the types of metaphors found).

In the Phase 1 qualitative exploration, corpus tools in the software program AntConc version 3.4.3w (Anthony, 2014) were used in the initial stages to first determine the most frequent words. Then the concordance and collocate tools assisted to narrow down the final text that was examined for metaphoric content. Anthony explained the concordance tool as viewing key words in context to see how words and phrases are typically used (p. 2), and the collocate tool as enabling investigation of (non) sequential patterns in the text based on the words that appear to the left and right of the target word(s) being investigated.

Although many of the most frequent words in the corpus were function words, the decision was made to initially focus on content words due to their importance in reading comprehension (e.g., Lam, 1984). Content words such as nouns, verbs, adjectives, and adverbs are differentiated from function words like prepositions, conjunctions, articles, determiners, and verb auxiliaries (Kimball, 1973). Additionally, Steen et al.'s (2010) BNC study revealed that prepositions and determiners were used metaphorically the most, over 30% of the time, followed by verbs, nouns, adjectives, and adverbs anywhere from 10–25% of the time. As such, a combination of prepositions, nouns, and verbs were examined in the final, deeper exploration of the corpus. A list of 24 collocates of the verb *is* and preposition *of*, combined with 21 of the most frequent nouns and verbs were the focus of the final sampling of concordances that were analyzed, to represent the most frequent collocations that students would encounter in their engineering reading material. Stratified random sampling (Teddlie & Tashakkori, 2009) was used, drawing a proportionate sample at random intervals, to ensure that each of the five engineering subtopics in the corpus (the strata) were reached and examined in proportion to their sizes. Examples of the final collocates sampled for metaphoric content include *function of*, *reaction is*, *value of*, *is shown*, and *of energy*.

To complete Phase 1, the collocations were analyzed for metaphoric content using an adapted version of the Pragglejazz Group's (2007) Metaphor Identification Procedure (MIP). This is a multistep process whereby text is analyzed and meaning determined in the context in which it appears, and if the text has other contemporary meanings in other contexts, a determination is made as to whether the meaning in the context in question is figurative, and in turn, metaphoric. The process is outlined in detail in Appendix B; the first step was skipped since the corpus was not read in its entirety. Steen and his colleagues (2010) updated the MIP (renamed to MIPVU) to consider both indirect (unsignalled) and direct (e.g., simile, signalled with like or as) forms of metaphor, as well as implicit expressions of substitution and ellipsis where referent words are substituted or omitted to avoid repetition and improve text cohesion (Cutting, 2002). However, that level of detail was not necessary for this study so the original MIP was used.

Drawing from the findings of the corpus exploration in Phase 1, Phase 2 consisted of designing and administering the metaphor comprehension test task, followed by the analysis of test responses. Although the initial intent was to include text from all five subtopic areas of the corpus, the text and embedded metaphors used in the test task were taken directly from the chemistry area. This subtopic area contained the highest proportion of metaphoric content based on the qualitative review (with a small amount of quantification), and the chemistry text was perceived as the simplest and easiest to understand, based on my intuitions as a non-STEM specialist and readability measures. The three paragraphs of text chosen for the test task were analyzed using the software program Coh-Metrix version 3.0. This program evaluates text on over 100 readability indices, including word and sentence length and count, and cohesion and coherence measures (Graesser et al., 2004). The 10 test metaphoric words and phrases embedded in the three paragraphs of text are summarized in Table 1. The metaphor test task was embedded in one iteration of the diagnostic assessment, as one of the three tasks in that part of the assessment, which students had 30 minutes to complete in class.

Table 1
Metaphoric Test Words/Phrases

Test Word/Phrase
introductory level
chemical connection
experience gained
employ
carrying out
led to a dead end
body of knowledge
are closely tied to
harnessing
relationship

Not every student provided a response to define each of the 10 metaphoric words and phrases. Thirty-one of the original 42 students provided at least one response, and a collective total of 209 responses. A 5-point scale was developed to determine the level of correctness or incorrectness and each of the responses were rated (See Appendix C for the scale descriptors). A second rater also rated a sampling of responses to determine inter-rater reliability. There was exact agreement 40% of the time and agreement within one scale descriptor (and on the same side of the scale) another 50% of the time, totaling approximately 90% agreement overall. Internal consistency was also calculated for responses where students had attempted at least half of the questions. Cronbach's alpha was acceptable at 0.79. Descriptive statistics were then calculated using SPSS version 22 to analyze how students performed on each of the 10 questions and on the metaphor comprehension task overall.

The final stages of quantitative analysis were completed in SPSS version 22 using nonparametric correlations (Spearman's rho) and t-tests (Mann-Whitney U). The correlations and t-tests investigated relationships among the metaphor test responses and students' first language (English/Other) and at-risk designation (yes/no) on the diagnostic assessment. Effect sizes were determined using Cohen's (1988) guidelines. Since SPSS version 22 does not provide effect sizes for Mann-Whitney U tests, these were calculated using the formula provided by Pallant (2010, p. 230).

Findings

The first research question, addressed in Phase 1 was: To what extent are metaphors prevalent in reading material used in first-year engineering courses? The corpus analysis revealed metaphoric content in every subtopic area of the corpus, but in differing relative proportions. The least amount of metaphoric content was found in the mechanics texts, while the greatest concentration of metaphoric content was observed in the chemistry and physics portions of the corpus. The most significant patterns to emerge regarding the types of conceptual metaphors were personification and metaphors related to family and relationships. One of the more interesting initial patterns to emerge was how the noun *atoms* was used metaphorically: individual atoms do not behave, atoms enter the solution, chemical bonds between atoms, network of atoms, neighbouring atoms, atoms are held together by, and atoms combine to achieve. Additional examples of the corpus analysis findings are provided in Table 2. The italicized text represents the collocations that were analyzed.

Table 2
Select Phase 1 Findings

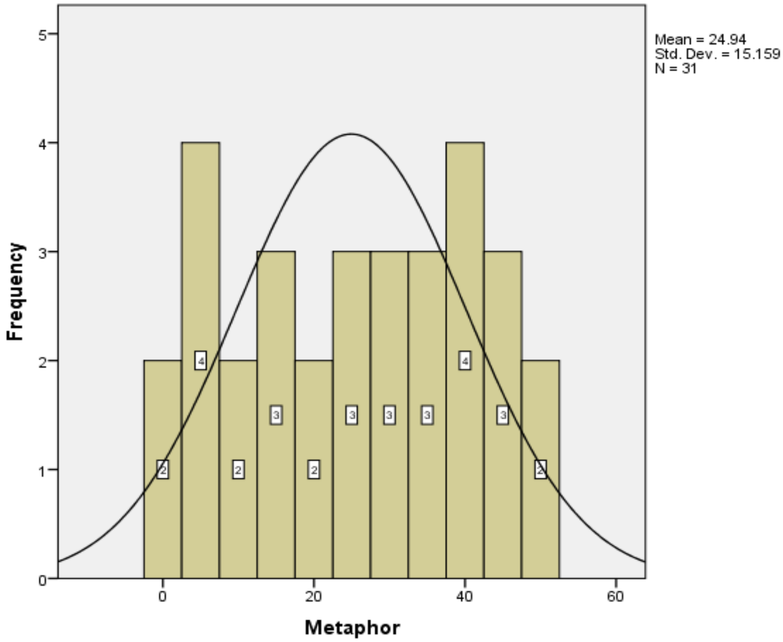
Calculus	Chemistry	Computers	Mechanics	Physics
…each *value of* the constant gives rise to…	One of the promising candidates *is called*…	...*program is* translated by the computer…	…a *force is* completely characterized…	…a magnetic *field is* set up whose strength is proportional…
…the table *of values* suggests…	All forms *of energy* are capable of doing work…	Line 3 now calculates and stores the *value of* the variable…	The *moment of* a couple can also be expressed by the vector…	The conservation *of energy* is a powerful tool for solving problems.

In Phase 2, the second and third research questions were addressed, namely, whether metaphor comprehension impacts reading comprehension of engineering texts; and whether a student's first language impacts comprehension of metaphors in English. Of the 31 students who attempted at least one response, the mean score out of a possible 50 was 24.94 with a standard deviation of 15.16. The rated responses are documented in Table 3. Students responded to items at the beginning of the test more frequently than items at the end of the test. Accordingly, the first two test items (introductory level, chemical connection) had the highest number of correct responses and the least number of nil responses. Items 3 (experience gained) and 6 (led to a dead end) also had a higher number of correct responses, while item 4 (employ) had the highest number of incorrect responses. As suggested by the standard deviation from the mean score result, the distribution of rated responses was not normal; it was bimodal, as illustrated in Figure 1. This revealed separate groups of low and high achieving students for the metaphor test task.

Table 3
Breakdown of Students' Rated Responses

Question	Responses per Scale Descriptor					Total Responses	Nil Responses
	1	**2**	**3**	**4**	**5**		
1	1	3	5	1	17	27	15
2	0	3	1	7	18	29	13
3	3	2	3	6	10	24	18
4	9	2	1	1	9	22	20
5	3	2	4	4	8	21	21
6	2	1	1	15	4	23	19
7	2	3	2	4	5	16	26
8	1	0	3	7	6	17	25
9	1	1	0	11	1	14	28
10	1	0	2	4	9	16	26
Totals	23	17	22	60	87	**209**	**211**

Figure 1
Metaphor task bimodal distribution of graded responses.



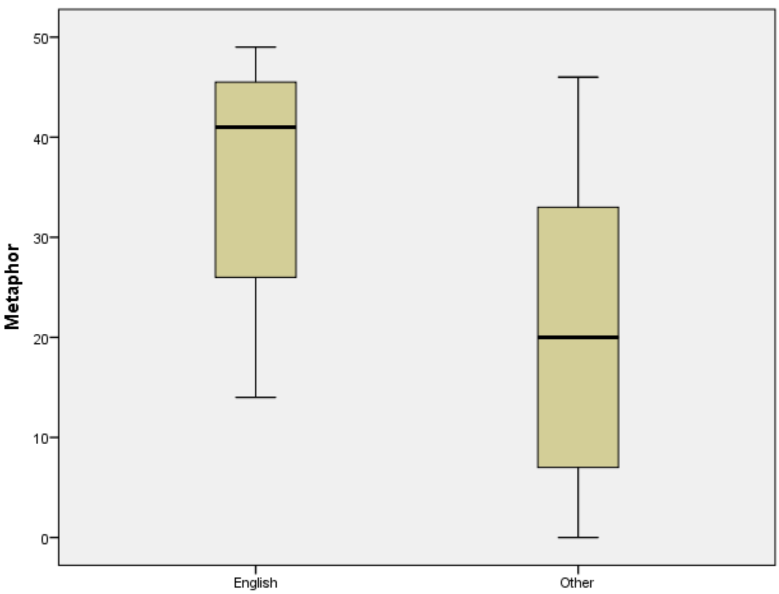
Inspection of students' responses to the metaphor test items revealed some literal interpretations, though there were a relatively low number of these types of responses overall. Item 4 (employ), which was the item with the most incorrect responses, evoked the most literal responses, including *worker*, *give work to*, and *apply to* instead of the non-literal meaning of use. Other examples of literal responses included *taking out* for item 5 (carrying out—doing), *use whole life in project* for item 6 (led to a dead end—did not go anywhere) and *learning people* for item 7 (body of knowledge—collection of what is known).

Correlation analysis was conducted to consider the metaphor test responses in relation to students' first language. The Spearman's rho results indicated a medium strength negative relationship, $r = -.43$, $p < .05$. These variables were also analyzed with a Mann-Whitney U test, which resulted in a negative relationship with medium effect size: $U = 39.5$, $z = -2.37$, $p < .05$, $r = .43$. The boxplot in Figure 2 illustrates the negative relationship found between first language and performance on the metaphor test task. The mean scores were about 40/50 for L1 students, and approximately 20/50 for L2 students; the English L1 students performed better on this task than the English L2 students.

Fox (2016) observed in her ongoing research with the diagnostic assessment that the integrated writing task scores were the most reliable indicators of students being at-risk of potentially having difficulties in their first year of engineering studies. As such, correlations were calculated for the metaphor test task and the writing task. The Spearman's rho result confirmed a significant, positive correlation $r = .44$, $p < .014$. These variables were also analyzed with a Mann-Whitney U test. These findings confirmed with a large effect size that those who did not perform well on the metaphor test did not perform well on the diagnostic assessment (particularly the writing task), and were more likely to be designated at-risk: $U = 34.0$, $z = -2.83$, $p < .01$, $r = .51$. Finally, Spearman's rho results for the metaphor test and at-risk variable confirmed a strong, positive relationship: $r = .52$, $p < .01$.

Figure 2

Comparison of metaphor test responses and students' first language.



Discussion

The Phase 1 findings answered the first research question about the extent of metaphors in the corpus of first-year engineering reading material. It was not surprising to find metaphoric content in each of the subtopic areas given what is known from the literature regarding metaphoric content in academic discourse generally, and STEM subjects specifically. It was also not surprising to see a great deal of personification. Lakoff and Johnson (1980) categorized this under the umbrella of ontological metaphors, which allow speakers to relate their experiences and concepts encountered to physical objects with dimensions. These can then be referenced, categorized, grouped, or quantified, which facilitates reasoning about them.

The distribution of metaphoric content among subtopics is of greater interest, with more in chemistry and physics, and the least amount in mechanics. I found the chemistry portion of the corpus the easiest to understand and physics one of the most difficult based on my intuitions as a native English speaker and STEM non-specialist, as well as readability measures. Intuitively it might seem as though more metaphoric content should make a passage more difficult to read than one with less metaphoric content. However, there are many factors that impact readability as is apparent with the volume of Coh-Metrix indices. In addition, it may be the case that readability is affected by the types of metaphors present, not just the volume, as was the case in Meissner's (2010) study. This would be an interesting area for further research. In addition, it would be interesting to see whether STEM specialists' opinions about the readability of subtopic areas of engineering text match my own.

Also interesting is that metaphoric content was more common when active voice was used, as demonstrated in the examples in Table 3. This is not something that was explicitly analyzed or even apparent at first, until a counter example appeared in the mechanics texts. One of the collocations examined was *is shown*, which is passive voice. No metaphoric instances were found because the use of this collocation was almost exclusively . . . *is shown in Figure* . . ., like in the example . . . *diagram of the pulley is shown in Figure*. . . . This of course does not provide conclusive evidence of metaphoric content in active verb constructions or the absence of metaphoric content in passive constructions. And even if this pattern was empirically confirmed, there are disciplinary norms for writing in active or passive voice. However, it would be valuable to undertake deeper corpus investigations to see if there are any patterns that could aid L2 classroom vocabulary and grammar instruction.

Phase 2 findings addressed the second and third research questions regarding the impact (if any) of metaphor comprehension on reading of the engineering texts and the effects (if any) of first language on metaphor comprehension. The wide range of students' scores, 15-point deviation from the mean, and bimodal distribution of scores suggest that metaphor comprehension did impact some students' ability to read the paragraphs excerpted from the corpus of first-year engineering reading material, and interpret the figurative language within the test passages. However, the impact was greater for those students whose first language was not English.

The bimodal distribution divided the test takers into distinct groups of high and low achievers on this task, or those who did and did not have an understanding of the metaphoric words and phrases. Closer inspection of these results revealed that almost all English L1 students received a passing grade on the metaphor task, whereas the majority of English L2 students received a failing grade. The strong and positive correlation and t-test results comparing the metaphor test responses with the diagnostic assessment at-risk designation indicates that those students who did not perform well on the metaphor test tended to not do well on the rest of the diagnostic assessment and particularly the writing task. As a result, these students were more likely to be designated at-risk of having difficulties in their first-year engineering studies.

Finally, the literal responses were proportionately quite small, but they were produced exclusively by English L2 students, which is consistent with Danesi's (1995) notion of the textbook literalness phenomenon. The metaphor task findings also align with existing research demonstrating the difficulties that language learners have with metaphor in English, and provide evidence from the Canadian postsecondary context. Despite this, the extent to which students' reading comprehension of first-year engineering reading material may be impacted cannot be concluded from these findings. Additional research would be required to determine this.

In considering the findings through the CMT lens, there are aspects that can be discussed from the theory's conceptual metaphor origins, as well as from Steen's contemporary form of the theory. The cultural specificity of metaphors has implications for the background knowledge or schemata that students need to understand some metaphoric referents. Although there are differences between cultural background and other forms of background knowledge that affect students' schemata that need to be teased apart, there is evidence in the literature relating to cultural background knowledge. Findings discussed in earlier research from Steffensen et al. (1979), and Floyd and Carrell (1987) provide insight into the difficulties caused by a lack of shared cultural knowledge. More recently, Meissner (2010) in her textbook study with primary school students found difficulties with metaphors that were not common in the students' language and culture. Lantolf and Thorne (2006) raised questions as to whether it is even possible to develop conceptual thinking in a second or additional language. Learning English as an additional language does not typically afford learners the same cultural exposure as first language speakers, although advances in technology and global exchange are contributing to lessen this gap. Further complicating the issue is the global nature and varying forms of English; it cannot be tied to one specific culture.

The systematicity and consistency (two facets of Lakoff and Johnson's conceptual metaphor theory) seen in the corpus analysis with the metaphoric content in active verb constructions and personification and family and relationship metaphors suggest that there may be patterned ways in which figurative language is used to talk about engineering concepts, although further research, such as more in-depth corpus investigations, is needed to confirm any patterns. Confirmed consistencies could be helpful for L2 instruction, even though students may still encounter comprehension issues when metaphoric referents are nonexistent or different than what is used in their first language, culture, and secondary school system. English L2 students may be socialized to some extent into the disciplinary norms of courses that they take in high school in their first language, such as math and science. However, there are differences in high school and university math and science courses as was demonstrated in the STEM diagnostic assessment studies cited earlier in this paper.

One of the aspects introduced to contemporary metaphor theory by Steen (2008) is the communicative dimension, which can be approached semiotically by looking at communicative functions, psychologically by considering individual processes and products, or socially by thinking about the shared processes and products of metaphor use. The focus in this study is on the domain of reading. Although an author may have communicative intent, there is no face-to-face exchange or reciprocity with her/his audience. An author must take for granted that the audience will receive and comprehend content as intended and readers take for granted that their representations are accurate interpretations of an author's intentions.

An example of how this can go wrong comes in the form of an anecdote heard at a conference. A researcher described a high-stakes English proficiency assessment context where a student mistakenly wrote about concrete (cement) building materials when instructed to provide concrete examples for how he would go about constructing a new park in a certain geographical location. The intent of the instructions was to ask what he would take into account and why more broadly, not what construction materials he would use. This highlights the need for caution and thought about wording used in assessment instructions. MacArthur (2010) also warned about metaphoric language used in verbal feedback. In terms of academic texts, it has already been discussed how metaphoric content is used to explain complicated or difficult concepts by using referents that should make the material more accessible. However, the cultural nature of metaphor complicates this notion. It may be the case, as noted by Steen (2011), that certain metaphors are so ingrained that they are accepted as conventional and are "culturally sanctioned models of reality" (p. 55). The question is how widespread is the acceptance of these perceptions of convention? Cross-cultural studies on metaphor use are shedding light on some of these questions, but much work remains.

Implications for EAP and First-Year STEM and Other Classrooms

This small-scale, exploratory study adds further evidence to the existing literature on the difficulties that English L2 students have with English metaphor comprehension, particularly in the Canadian postsecondary context. For instructors wishing to incorporate metaphor in their language classrooms, awareness raising is a good place to start (e.g., Boers, 2000), especially if the level of explicit exposure to English metaphor is unknown or low, or the class consists of low-proficiency learners. Awareness-raising activities could also be used in listening exercises. Furthermore, to take from Steen's ideas on social metaphor use through shared processes and products, this could open the door in language classrooms for cross-cultural discussions of how metaphor is used and understood. A valuable resource to explore this is the 2003, *18*(4) issue of *Metaphor & Symbol* focusing on cross-cultural variation.

Although there is debate in the field regarding EAP pedagogical approaches (e.g., Li, 2017), those instructors that incorporate discipline-specific material or who use thematic topics could incorporate metaphor awareness-raising and comprehension activities based on disciplinary reading material. Further research is required to confirm any amount of generalizability among the findings in this study to other contexts, but the chemistry texts appeared to be the easiest to read and contain the most metaphoric words/phrases. As such, introductory chemistry reading material may be a good place to start to introduce STEM students to metaphors they may encounter in their first-year university reading material. Research has been scant into metaphor use in other disciplines, but there are some options available that may be helpful in analyzing readings in other topic areas (e.g., metaphor studies into business and economics by Boers, 2000; Herrera Soler & White, 2012; and Littlemore, 2002).

Littlemore and Low (2006) were referenced earlier in stating the need to develop metaphoric competence in reading and listening before writing and speaking, but the latter skills are still important. University students need to communicate with other students, staff, and instructors in both formal and informal settings, in and out of the classroom, and in administrative, learning, and assessment contexts. However, students whose first language is not English often find spoken communication and spoken academic tasks difficult (e.g., Berman & Cheng, 2001). Research into metaphors in writing and speaking is sparse, with a few notable exceptions (Hoang & Boers, 2018; Kathpalia & Carmel, 2011; MacArthur, 2010). In language classrooms, speaking could be addressed jointly with listening by analyzing metaphors heard in speech and then focusing on targeted metaphoric expressions in speaking activities. Similar integrated activities could be done for writing. Word lists and corpora may be helpful in facilitating these exercises (e.g., Skorczynska Sznajder, 2010; Ward, 2009).

Finally, support staff, instructors, and teaching assistants who interact with students, particularly first-year students who may already be struggling to adjust to new academic processes and subject content, could aim to be more conscious of possible issues that may arise from L2 students' inability to recognize metaphoric content, its misinterpretation, or incorrect use. Comprehension issues may arise in both academic and administrative communication onsite, online, and in both speech and writing. The first-year classroom may be a particularly challenging forum since these classes are often large and dependent on lectures for content delivery (e.g., Briggs et al., 2012; Gilbert et al., 1997; Pascarella & Terenzini, 2005; Trautwein & Bosse, 2017; Trigwell & Prosser, 2013). When it comes to classroom written materials and textbooks, there may be established discipline-specific terminology and ways of explaining subject-specific concepts that are useful to maintain. As such, the goal is not to avoid the use of metaphoric language, which would be an impossible task. However, awareness coupled with EAP curricula addressing metaphor comprehension could be the answer in helping to bridge the gap (e.g., Ferreira & Zappa-Hollman, 2019).

Limitations and Conclusion

There are limitations to this study that impact what can be deduced from the findings. The small cohort of students who began their studies in the winter term and wrote the diagnostic assessment was much smaller than a typical fall cohort. This small sample size and the exploratory nature of the research render the results not generalizable beyond this cohort of students. Since overall English language proficiency was not tested, there could be variability among different student groups, including EAP and Generation 1.5 students, that may have affected the diagnostic (and metaphor task) assessment outcomes. A number of test takers did not attempt some, or all, of the metaphor test task and it cannot be assumed that this was due to a lack of understanding of the metaphoric words/phrases. The metaphor task was at the end of a 3-part diagnostic assessment. Part 3, which contained two other tasks including a writing task, was limited to 30 minutes to complete, and no adjustments were made to compensate for the added metaphor comprehension task. Some students may have run out of time or energy to respond.

Assumptions were made as to what constitutes *metaphor comprehension* in this context. Students were asked to define only 10 metaphoric words and phrases, as they appeared in the context of the paragraphs of text from the engineering corpus, in their own words. It is arguable whether this demonstrates metaphor comprehension given the small number of questions and exclusive focus on lexical and conceptual metaphors. Further research is required to better define the concept of metaphor comprehension as a test construct, but it is encouraging to see that this is an active area of investigation (e.g., O'Reilly & Marsden, 2020). Finally, while an attempt was made to use authentic reading materials for the metaphor comprehension task by drawing directly from the corpus, this is now several years old. This content may no longer be reflective of the reading material used in first-year engineering courses at this institution and may never have been reflective of what reading material is used in other engineering programs in other postsecondary institutions.

Despite these limitations, the findings of this study are consistent with existing literature on metaphor comprehension and provide further evidence of the difficulties that language learners have with metaphor in English in the domain of reading, particularly in the Canadian postsecondary context. Additionally, the findings provide further evidence of metaphoric content in academic texts, and more specifically in STEM subjects. However, despite knowing that metaphor comprehension is difficult, the extent to which the inability to recognize, interpret, and/or produce metaphors in English impedes scholastic success and in precisely what ways are still unknown. A number of questions remain including whether problems with metaphor comprehension simply add to the time English L2 students take to read academic text or impact their reading in some other way, how much of the metaphoric content they recognize and understand, and the extent to which metaphoric words and phrases not recognized, understood, or misunderstood impedes comprehension of whole texts.

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Appendix A. Metaphor Comprehension Test Task

Part 3.3. Reading for detail in Engineering

DIRECTIONS: The paragraphs below (A., B., and C.), are taken from first-year chemistry for engineering textbooks. In the space provided on the right-hand side of the page (see Comment boxes), please describe in your own words the meaning of each of the underlined words/phrases in the paragraphs.

A. Compared with other subjects, chemistry is commonly believed to be more difficult, at least at the introductory level. There is some justification for this perception; for one thing, chemistry has a very specialized vocabulary. However, even if this is your first course in chemistry, you already have more familiarity with the subject than you may realize. In everyday conversations we hear words that have a chemical connection, although they may not be used in the scientifically correct sense. Examples are "electronic," "quantum leap," "equilibrium," "catalyst," "chain reaction," and "critical mass." Moreover, if you cook, then you are a practicing chemist! From experience gained in the kitchen, you know that oil and water do not mix and that boiling water left on the stove will evaporate.

B. All sciences, including the social sciences, employ variations of what is called the scientific method, a systematic approach to research. For example, a psychologist who wants to know how noise affects people's ability to learn chemistry and a chemist interested in measuring the heat given off when hydrogen gas burns in air would follow roughly the same procedure in carrying out their investigations. The development of science has been irregular and sometimes even illogical. Great discoveries are usually the result of the cumulative contributions and experience of many workers, even though the credit for formulating a theory or a law is usually given to only one individual. For every success story, however, there are hundreds of cases in which scientists have spent years working on projects that ultimately led to a dead end, and in which positive achievements came only after many wrong turns and at such a slow pace that they went unheralded. Yet even the dead ends contribute something to the continually growing body of knowledge about the physical universe.

C. Energy production and energy utilization are closely tied to the quality of our environment. A major disadvantage of burning fossil fuels is that they give off carbon dioxide, which is a greenhouse gas. That is, it promotes the heating of Earth's atmosphere. Carbon dioxide, sulfur dioxide and nitrogen oxides result in acid rain and smog. Harnessing solar energy has no such detrimental effects on the environment. The energy contained in tidal waves can also be harnessed to perform useful work, but the relationship between tidal waves and chemistry is minimal.

Appendix B. Metaphor Identification Procedure (MIP)

The Pragglejazz Group's (2007) MIP is as follows (p. 3):

1. Read the entire text–discourse to establish a general understanding of the meaning.

2. Determine the lexical units in the text–discourse.

3. (a) For each lexical unit in the text, establish its meaning in context, that is, how it applies to an entity, relation, or attribute in the situation evoked by the text (contextual meaning). Take into account what comes before and after the lexical unit.
(b) For each lexical unit, determine if it has a more basic contemporary meaning in other contexts than the one in the given context. For our purposes, basic meanings tend to be
—More concrete [what they evoke is easier to imagine, see, hear, feel, smell, and taste];
—Related to bodily action;
—More precise (as opposed to vague);
—Historically older.
Basic meanings are not necessarily the most frequent meanings of the lexical unit.
(c) If the lexical unit has a more basic current–contemporary meaning in other contexts than the given context, decide whether the contextual meaning contrasts with the basic meaning but can be understood in comparison with it.

4. If yes, mark the lexical unit as metaphorical.

Appendix C. Rating Scale Descriptors for the Metaphor Test Task

Code	Scale Descriptor	Alternate Description
1	Incorrect response—unrelated	Clearly no understanding (no doubt)
2	Mostly incorrect, but some part slightly related (a stretch)	Very little understanding demonstrated (major doubt)
3	Somewhat correct/seems like response is on the right track, but something is off	Some understanding demonstrated but difficult to judge whether or not concept is understood (inconclusive)
4	Mostly correct; something minor may be a bit off	Understanding demonstrated for the most part (minor doubt)
5	Correct response	Clear understanding (no doubt)