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Creating an Institution-Specific Science and Engineering Academic Word List for University Students

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This research study considers the problem of Japanese university students who are studying the sciences in their native language, but who also may be expected to do at least part of their reading through textbooks written in English. The article presents a Science Textbook Word List (STWL), derived from a 700,000-word academic corpus compiled from English-medium textbooks intended for science majors. The STWL contains 309 word families, which accounts for 13.4% of the tokens in the science textbook corpus under study. The high word frequency and the wide text coverage of academic vocabulary throughout the science textbooks confirm that academic vocabulary plays an important role in science textbooks. The study also found that the STWL provided better coverage of the studied corpus than the widely used Academic Word List (AWL) (Coxhead, 2000), and another science word list (Coxhead & Hirsh, 2007). These results demonstrate that corpus-specific word lists provide more coverage of the intended texts with fewer items. This is of benefit to the students as the amount of learning time can be significantly reduced, and the effort put in to learn such lists is well repaid by the opportunity for using the vocabulary.

Keywords: word list, lexical coverage, vocabulary, EFL

Introduction

Many students enrolled as science majors in Asia attend lectures held in their first language, yet are required to read textbooks that are written in English (in Taiwan, see Hsu, 2014; in Indonesia, see Nurweni & Read, 1999; in Iran, see Valipouri & Nassaji, 2013; and in Thailand, see Ward, 2009). As knowledge of academic vocabulary is seen as an indispensable component of both academic reading ability and success (Dreyer & Nel, 2003; Nagy & Townsend, 2012; Schmitt, Jiang, & Grabe, 2011), it is imperative for learners to comprehend what is read. Unfortunately, due to the large amount of vocabulary found in English-medium academic texts, expecting students to know or learn this vast quantity of words may prove to be an unrealistic assumption of the teachers.

One way to assist science majors with reading comprehension is to narrow the domain of language, providing learners with the specific lexical knowledge necessary to function in such an academic context. Nation (2001, 2008) recommends that students with lower-levels of English should focus on the general high-frequency vocabulary, such as West's (1953) General Service List (GSL), while higher-level students who already have a strong command of the basic core vocabulary, such as many science majors, should focus on the lower frequency technical or academic vocabulary.

Technical or domain-specific words are vocabulary related to a particular discipline (Martin, 1976).

These items occur frequently in a specialized text of a subject area, but do not occur (or very rarely occur) in other fields (Nation, 2001). For example, words such as *torque, thermodynamics, concave, refraction,* and *electroscope* are examples of technical vocabulary that science students would encounter while studying physics. Researchers have argued that technical terms such as these do not pose a major difficulty for English for Specific Purposes (ESP) students in the sciences because they are central to students' specialized areas and thus are often used in lectures in the classrooms or tend to be bolded or glossed in textbooks (Farrell, 1990; Strevens, 1973).

Academic vocabulary, also known as *general academic words, content vocabulary* (Baumann & Graves, 2010), or *sub-technical vocabulary* (Baker, 1988), is defined as "formal, context-independent words with a high frequency and/or range of occurrence across scientific disciplines, not usually found in basic general English courses; words with high frequency across scientific disciplines" (Farell, 1990, p. 11). Examples of lexical items that can be found frequently across academic domains include *analyze, conduct, document, project* and *sum.* Some researchers (Anderson, 1980; Shaw, 1991; Thurstun & Candlin, 1998) have found that it is this non-specific, academic vocabulary that proves problematic for learners. Worthington and Nation (1996) and Nation (2001) suggest that this is in part due to academic vocabulary not being found in a text as often as high-frequency vocabulary. Because of this infrequency of vocabulary input, students lack opportunities for incidental learning. Furthermore, because academic vocabulary is generally not a part of subject-matter content, it tends to be ignored by subject-matter teachers, and one reason is that teachers may assume that their students already know them (Farrell, 1990). The problems associated with academic vocabulary are a cause for concern because academic vocabulary accounts for approximately 10% coverage of any written academic text (Coxhead, 2000; Nation, 2001), leading Laufer and Nation (1999) to conclude that ESP learners cannot effectively deal with reading materials without sufficient knowledge of academic vocabulary.

Due to the challenges learners may face when confronted with academic vocabulary, researchers have constructed academic word lists. These lists have identified a set of particular words that occur with high enough frequency in academic subjects that students should spend time learning them. One such list is the Academic Word List (AWL), (Coxhead, 2000). It is a general academic word list compiled from a variety of academic texts of various disciplines. Because it can assist with the comprehension of academic reading materials in universities, the AWL is widely cited in vocabulary research, and has inspired a wide range of pedagogic materials. The AWL is still often the word list of choice by academic instructors (Bannister, 2016).

There are also word lists that are more subject-specific in nature. They allow learners to focus on specific vocabulary that are related to their academic majors. A few examples of these types of lists have been created in business (Hsu, 2011), engineering (Ward, 2009), science (Coxhead & Hirsh, 2007), and nursing (Yang, 2015). These word lists prove beneficial to students who specialize in a particular discipline, attend lectures in their native language, and yet also need to understand textbooks or supplementary material written in English.

Although all the aforementioned high-frequency academic word lists support ESP learners, they all suffer from one major drawback – they are limited to contextual factors. Nation (2016) points out that each academic discipline has its own specific vocabulary that is closely related to the content involved in that area. Word lists then are influenced by the collection of the specific texts which they are created from, which means that each word list is best suited for the learners they are intended for. Consequently, of all of the word lists created, none have precisely addressed the vocabulary needs of *our* science students studying at a Japanese university.

Because undergraduate science majors in a public university in Japan are faced with the same textbook and academic word challenges as their Asian counterparts, specific word lists are needed for them. This study looks to alleviate this academic reading burden by targeting English textbooks that the science students would most likely encounter in their studies and creating an academic science and engineering word list for these students. It is hoped that this new word list will reduce the vocabulary gap between the amount of vocabulary found in the textbooks and what is understood by the undergrads at the university.

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Literature Review

Academic Word Lists

Academic word lists created with the intention of helping students learn the vocabulary they would most likely encounter during their university studies, have been around for at least forty years (e.g., Campion & Elley, 1971; Ghadessy, 1979; Lynn, 1973; Praninskas, 1972; Xue & Nation, 1984). Because these lists were based on various corpora of academic materials of a smaller and limited nature, two new academic word lists have been recently created: the Academic Vocabulary List (AVL) and the New Academic Word List (NAWL) (Browne, Culligan, & Phillips, 2014; Gardner & Davies, 2014). These researchers used a corpus of 120-million words, and 288-million words respectively, in order to create a more robust list representing contemporary academic language. However, these lists have yet to replace the more established 570-word AWL developed by Coxhead (2000).

Coxhead's AWL (2000) was created from a corpus of 3.5 million words compiled from academic texts from four faculty areas (arts, commerce, law, and science). Each of these four subject areas included texts from seven specific disciplines, such as history, economics, criminal law, and botany, to make a total of 28 different subject areas. In order to be included in the AWL, the words had to meet three criteria: (1) *specialized occurrence* – they had to be outside of West's General Service Word List (West, 1953), (2) *frequency* – they had to occur at least 100 times in the corpus, and (3) *range* – the words needed to represent the lexis of a variety of academic disciplines so the words had to occur at least 10 times in each of the four faculty areas and in at least 14 of the 28 specific disciplines.

Coxhead (2000) found that in her 3.5-million-word academic corpus, the GSL covered 76.1% of the words, and the AWL covered another 10.1%, resulting in a combined total coverage of 86.1%. The high coverage of the AWL has been confirmed with other academic corpora representing a variety of academic disciplines (Chen & Ge, 2007; Cobb & Horst, 2004; Huang, & Chang, 2009; Hyland & Tse, 2007; Martinez, Beck, & Panza, 2009; Valipouri & Nassaji, 2013; Vongpumivitch , Li, & Qian, 2010), thereby indicating that the AWL possesses generalized validity.

Despite the consistent 10%-word coverage of the AWL in academic texts, its effectiveness as an instrument for the development of academic vocabulary in ESP courses has been questioned. One of the first published independent evaluations and criticisms of the AWL came from Hyland and Tse (2007), who built a corpus of 3.3 million words from multiple disciplines (sciences, engineering, and social sciences), with texts which represented the range of sources students would be asked to read in a university setting. They showed that the AWL did provide the 10% coverage of the academic text in their corpus as Coxhead had suggested; however, the distribution was not the same for all the disciplines in the corpus. The AWL appeared to be most useful to students studying in the computer sciences, with 16% of the words were covered by the AWL, and least useful to biology students, with only 6.2% coverage. They concluded that although the use of a general academic word list may be attractive, there appears good reason to approach the list with caution because not all learners would receive the same benefits across diciplines.

Other studies that have profiled the AWL on different corpora (Chen & Ge, 2007; Li & Qian, 2010; Martinez et al., 2009; Paquot, 2007) also concluded that the list is too general, which could expose learners to more vocabulary than they may need, while at the same time deprive learners of the specific vocabulary that would prove more beneficial. Thus, instead of teachers and learners focusing on a list that was created from a corpus based on many different subject areas, they may be better served with a list based on their area of study. This means, for example, that learners partaking in science classes would most likely benefit more from learning lexical items directly related to their courses, for example, *cell, energy,* or *membrane*, as opposed to learning words on the AWL such as *legal, legislate, corporate,* or *finance,* which are intended for law or finance-oriented disciplines.

Discipline-Specific Word Lists

Perhaps in recognition of the aforementioned shortcoming of the discipline-crossing AWL, researchers have produced lists that focus on the academic vocabulary used in single disciplines. As Table 1 shows, some of the discipline-specific word lists include words that overlap with the AWL, while others created lists without the AWL. The reason for two types of lists are that the more discipline-based lists are intended to replace the AWL, while the others were created to supplement it.

TABLE 1
Previous studies on discipline-specific word lists.

Past research	Word list	Number of words	Coverage
Konstantakis (2007)	The Business Word List (BWL)	560, no AWL words	2.79%
Lui and Han (2015)	Environmental Academic Word List (EAWL)	458 with 318 from AWL	15.43%
Wang et al. (2008)	Medical Academic Word List (MAWL)	623 with 342 from AWL	12.24%
Yang (2015)	A Nursing Academic Word List (NAWL)	676 with 378 from AWL	13.64%
Hsu (2014)	Engineering English Word List (EEWL)	729 with 304 from AWL	14.3%
Mundraya (2006)	Student Engineering Word List	1200 with number from AWL not available	Not available
Ward (2009)	Basic Engineering List (BEL)	299 with number from AWL not available	16.4%
Coxhead & Hirsh (2007)	Science Word List	318, no AWL words	3.79%

Science Word Lists

Words lists that are relevant to this study include the ones developed specifically for science majors. Mundraya (2006) has argued that vocabulary should be given more attention in the ESP classroom and established the Student Engineering English Corpus (SEEC). This corpus contains nearly two million words and was selected from engineering textbooks in 13 sub-disciplines to produce an academic word list containing 1260 word families and 9000 word-types for engineering students. Unfortunately, she did not provide the percentage that this list covered in her corpus, but indicated that the words in her list are intended for engineering students regardless of fields of specialization, as the word families are frequently encountered in engineering textbooks compulsory for all engineering students.

In order to help his low English proficiency engineering students studying in Thailand, Ward (2009) created the Basic Engineering List (BEL) based on a corpus of 271,000 words. This list is unique in that the corpus is relatively small and the BEL is made up of only 299 word-types. Some of the words in the BEL belong to the same family. For instance, *used*, *use*, and *using* come from the same headword *use*, but they are all listed in the BEL. Ward argued that since his students were very poor in their English proficiency, they had limited vocabulary and word-forming knowledge and that a list with word types would prove easier than a list of word families. The BEL had 16.4% coverage of tokens in his corpus. This highlighted the excellent coverage that a specific list can give.

Coxhead and Hirsh (2007), responding to the criticism regarding the unbalanced nature of the AWL in the science subcorpus, produced a science-specific word list for EAP students. This list was developed by creating a corpus from written academic science texts from 14 subject areas in the sciences, ranging from biology to veterinary and animal science, resulting in a corpus of 1,761,380 individual tokens. After eliminating all words from West's (1953) GSL and Coxhead's (2000) AWL, a science specific word list of 318 word families was created. This new science specific list covered 3.79% over the running words of the fourteen science subject areas in the corpus. When this new science word list was combined with the GSL (71.52%) and the AWL (8.96%), it gave a total coverage of 84.27% of the science corpus for first year undergraduate science students.

The discipline specific word lists allow students to focus on lexis related to their majors, and appear to assist learners in their English academic studies. Unfortunately, as previously mentioned, they were not created with researchers' Japanese university students in mind, and thus have their shortcomings.

Both Mundraya (2006) and Ward's (2009) engineering word lists include vocabulary from West's

(1953) GSL. These high frequency words may be deemed necessary in Thailand, but they are not suitable for the present context at the university in Japan. At universities in Japan, third-year high school students are generally recruited through entrance exams which require students to read and answer questions about a variety of topics where a majority of the lexical items can be found in the GSL. Those students wishing to enter the science programs at the more prestigious public universities in Japan need a strong grasp of the GSL just to pass the entrance exams. As such, the researchers believe most of the students attending the university in Japan already have a strong grasp of the general vocabulary. Since class time is limited, it is essential for the students to shift their learning focus from general vocabulary on to more specific words as required by their majors.

Coxhead and Hirsh's (2007) science word list does not include words from either the GSL or the AWL. This means students must learn the 570 word families from the AWL, as well as an additional 318 word families from the science-specific word list, which represents a total of 886 new word families. This amount of words may not be excessive for first-year ESL undergraduate students at the universities where the research by Coxhead and Hirsh was conducted. At these institutions, English is the medium of instruction for all classes, and students are exposed to English outside of the classroom. The present study, in contrast, was carried out in Japan, which is an English as foreign language (EFL) environment. This means that the language of instruction in most subjects is not in English and that students have few opportunities to be exposed to English once they leave the classroom. With limited exposure to English, the amount of times they will encounter new words would be limited compared to their ESL counterparts, who have a better chance of coming across newly taught vocabulary both in and out of the classroom. Nation's (2001) summary of the research on the number of repetitions necessary to learn a lexical item found that for learners to acquire new vocabulary, they need to be exposed to the word from between 5 to 20 times. This suggests that providing learners with an excessively large number of words to be learned could prove to be overwhelming for EFL students, due to a lack of exposure. A list with fewer words would likely be a more realistic goal for ESP students in Japan to learn.

Other word lists that were intended for EFL students, such as Hsu's (2014) 729 engineering word list or Valipouri and Nassaji's (2013) chemistry academic list of 1400 words, also contain too many lexical items. Because classroom time is limited and because most courses have other objectives in addition to vocabulary learning, word lists that are around a thousand words are too long. When a word list becomes the size of a small book it is overwhelming for teachers and students alike. What is needed is a smaller list. Webb and Chang (2012) suggested that a goal of 400 English words a year could be achievable. Their research with 166 students studying in Taiwan found that over two 15-week semesters that the vocabulary growth of the students ranged from 18 to 430 words a year. They stress it is easier to start with a realistic number of words, because more words can easily be added once the vocabulary goals have been met. It would seem a word list containing fewer items benefits both teachers and students alike. It allows teachers to feel that the amount of words could be covered in a one-year course, and that it would be a much more attainable learning goal for the students.

Furthermore, it should be noted that for this research, the word '*science*' is used in a broad sense in that it included subjects not only specifically from the sciences, such as biology, chemistry, and physics, but also from the field of engineering. This was also the case with the science wordlist created by Coxhead and Hirsch (2007). Although science and engineering do have fundamental differences (i.e., better understanding of the laws of nature verses mastering these laws for usable end results), basic knowledge about both disciplines would be beneficial for the first- and second-year students at the science and technology university in Japan where this research was conducted. Therefore, the two disciplines are combined for the study. The aforementioned word lists are too specific for the students at an early stage of their university education. As a result, a word list is needed specifically aimed for the first- and second-year students who need general science academic vocabulary for their readings related to the sciences. After the second year of a general science education, students then specialize in a specific science discipline where they will be exposed to the more discipline-specific and technical vocabulary. At that time, the more specific word list for engineering or chemistry or any other science field may prove

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beneficial.

To this end, this study has two main aims: a) to create a reliable, yet manageable word list of academic words from a corpus that reflects the lexis encountered in textbooks for science and engineering majors studying at a university in Japan, regardless of the field of specialization within those disciplines, and b) to compare the researchers' university science-specific academic word list with other academic word lists to measure the overlap and difference in coverage. Accordingly, this research attempted to address two research questions as follows:

1. Beyond the 2000-word level, which lexical items occur with reasonable frequency and range in a corpus of science textbooks for a specific academic institution?
2. Do the words that occur with high frequency and range provide better coverage of the corpus compared to the AWL (Coxhead, 2000) and the science word list (Coxhead & Hirsh, 2007)?

Methodology

The Compilation of the Corpus

This study created a corpus of 704,237 words (the Science Textbook Corpus) from twelve English-language science textbooks across four main science subject areas: biology, chemistry, physics, and engineering. Three textbooks were selected from each of the aforementioned sub-disciplines, and they were chosen because they were either university-level standard textbooks for science and engineering majors or because they were recommended by the science and engineering professors. All the textbooks in the corpus were purchased by the researchers, photocopied, scanned, converted into machine-readable form, and then saved into text files. Pages from textbooks that contained large visuals were left out during the photocopy stage of the research, and other textual components such as charts, diagrams, graphs, and pictures were removed in the scanning stage. This allowed the software used for analyzing the data to read the text files. The computer-readable texts were then stored in the corpus. Finally, the texts and corpus were classified. The corpus was composed of twelve text files that were grouped into four subcorpora containing three files for each of the main subjects represented to give each subject balanced representation. The files from each textbook can be found in Table 2.

TABLE 2
Composition of the Science Textbook Corpus

Number	Text file	Tokens
1	Biology	70,012
2	Cell Biology	51,980
3	Molecular Biology	73,754
4	Inorganic Chemistry	68,315
5	Organic Chemistry	36,293
6	Physical Chemistry	62,470
7	Ordinary Physics	87,970
8	Physics	67,305
9	Thermodynamics	34,616
10	Electrical Engineering	27,670
11	Mechanical Engineering	27,958
12	Chemical Engineering	92,307
Overall		700,650

Due to the fact that a majority of the Science Textbook Corpus was compiled from textbooks recommended by professors, the number of words in each textbook dictated the number of words to be used in the corpus, which meant the total number of words in each sub-discipline was not identical. This was a limitation of the study as the number of words taken from each textbook should be the same. This should be done in future studies in order to avoid a word list being skewed towards textbooks with higher frequency counts. However, despite this limitation, it is believed that the Science Textbook Corpus represents a comprehensive picture of the actual written discourse that the science students are recommended to read and understand at the earlier stage of the undergraduate education at the university where the research was conducted.

The present study used the computer software program *Range* (Nation & Heatley, 2007) for the lexical analysis, profiling, and creation of the university science textbook word list. This software uses the GSL and AWL as files and it is available as a free downloadable zip file at https://www.victoria.ac.nz/lals/about/staff/paul-nation - vocab-programs. The GSL is divided into two files, one containing the first 1,000 most common words and another file containing the second 1,000 most common words. The words in the third file are from the AWL. The user can load one or more texts, and then the program tells which word band the words in the text(s) belong to. Words that are not in either the GSL or AWL are also provided. The program can also record the number of files that were used in the analysis and the exact file in which each word occurred. Some useful features of the software are that it can also sort the words in alphabetical order and in order of range (i.e., in how many different texts each word has occurred) and frequency. Another benefit of using RANGE is that it is possible to create your own word list and examine the frequency and range of texts with that list.

Word Selection Criteria

This study followed Coxhead's (2000) criteria of specialized occurrence, range, and frequency with some adjustments in the development of the word list. First of all, specialized occurrence was ensured because all words in the list had to be outside the first 2000 most frequently occurring words of English, which was based on West's (1953) GSL. Next, Coxhead only included words that appeared in 50% of the 28 subject areas. As our study only included four subject areas, words had to appear in at least three out of the four subjects to be considered for our word list. Finally, for words to be included in the AWL, they had to occur at least 100 times in Coxhead's 3,500,000-word corpus. Although our corpus is one fourth of that size, the minimum frequency of a word to be included in our list was 50 times rather than 25 times in order to ensure a higher coverage of the text being analyzed and to keep the total number of words on the list to a minimum.

To summarize, for words to be included in the Science Textbook Word List, and be consistent with Coxhead's (2000), Wang et al.'s (2008), and Yang's (2015) selection process, they had to meet the following criteria:

1. *Specialized occurrence*: The words included had to occur outside of the GSL.
2. *Range*: The words had to occur in at least three or more of the subject areas.
3. *Frequency*: The words had to occur at least 50 times in the corpus of science textbooks.

Once the GSL words were eliminated, potential candidates for the list were identified based on an initial analysis of frequency and range using the RANGE program. As the aim of this study was to focus on academic words that students may have difficulty learning, abbreviations, proper nouns, and symbols were cleared from the list. Coxhead (2000) also followed this procedure, because these are words that are most likely to be known or considered to have a minimal learning burden.

Lastly, the authors followed Coxhead's (2000), Wang et al.'s (2008), Coxhead and Hirsh's (2007), and Hsu's (2014) criteria and expanded the remaining words to families based on Level 6 of Bauer and Nation's (1993) scale. When making his engineering word list, Ward (2009) determined that his students had little word-forming knowledge of English, and therefore, used tokens as the unit for inclusion of his word list. However, when considering our students' English abilities and that the list was created to assist with reading comprehension, word families were chosen over word types. The final version of the list contains 309 word families and is titled the Science Textbook Word List (STWL). The full list of headwords can be found in Appendix 1.

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Results and Discussion

In the following we present results with discussion in accordance with the two research questions in our study.

The Science Textbook Word List and Coverage of Corpora

The first research question asked which lexical items beyond West's (1953) GSL occur frequently across a range of academic science textbooks. The STWL contains a total of 309 word families which satisfied the selection criteria of specialized occurrence, range, and frequency. Some of the most frequent word families in the STWL are *cell, molecule, electron,* and *figure*. Table 3 displays the 20 most frequent word families that could be found at least fifty times in each subcorpus in the STWL. These families also occurred in all four of the subcorpora.

Other word families such as *gene, enzyme,* and *mutate,* appeared in the corpus frequently enough to be included in the list of top 20 word families; however, these word families were excluded from the STWL because they only appeared in one or two of the subcorpora, thus making them too technical or discipline-specific. To be included in the word list, a word family had to be found in at least three of the subcorpora. These criteria followed what was done by Coxhead (2000) in creating the AWL in that range took precedence over frequency because "a word count based mainly on frequency would have been biased by longer texts and topic-related words" (p. 221). So, a word family like *protein*, which appears in the corpus 1941 times in the biology and chemistry subcorpus, was not included in the STWL because it would only directly benefit students studying those specific subjects. Giving range priority over frequency ensures a majority of the science majors benefited from the word list.

TABLE 3
The top 20 word families of the STWL

No.	Headword	Frequency	No.	Headword	Frequency
1	cell	3331 (4)	11	nucleus	443 (4)
2	molecule	2524 (4)	12	carbon	408 (4)
3	electron	1584 (4)	13	species	396 (4)
4	figure	1573 (4)	14	hydrogen	356 (4)
5	atom	1544 (4)	15	coil	344 (4)
6	ion	858 (4)	16	dense	327 (4)
7	acid	854 (4)	17	circuit	326 (4)
8	magnet	582 (4)	18	rotate	324 (4)
9	fluid	521 (4)	19	absorb	308 (4)
10	conduct	475 (4)	20	organic	303 (4)

Note: The number in brackets indicates the range.

By using the STWL as the base words in the RANGE software, it was found that the STWL accounts for 13.4% of the 700,650 running words in the science textbook corpus. A breakdown of the coverage of all the individual textbooks and for the subcorpora of biology, chemistry, physics, and engineering can be found in Table 4. The list appears to put chemistry students at a slight advantage as it covers 15.9% of the chemistry subcorpus. The coverage of biology and engineering is quite similar at 14.4% and 13.5% respectively. Finally, the coverage of physics at 10.2% is the lowest of the four subject areas.

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TABLE 4
Lexical coverage of the STWL over each textbook and subject area.

Corpus	Coverage of the STWL (%)
Science Textbook Corpus	13.4
Biology Subcorpus	14.4
Chemistry Subcorpus	15.9
Physics Subcorpus	10.2
Engineering Subcorpus	13.5

The data in Table 5 indicates the coverage of the GSL (West, 1953) and the STWL in the Science Textbook Corpus. The GSL provided 72.3% coverage of the entire corpus, only 67.9% of the chemistry subcorpus, and a much higher coverage of 79.6% of the physics subcorpus. This indicates that the chemistry textbooks contain a lower percentage of high frequency vocabulary and are more academic or technical in nature, thereby accounting for the higher level of coverage from the STWL. The physics subcorpus, on the other hand, contains up to 11.7% more high frequency words from the GSL when compared to the other subcorpora, thereby limiting the STWL to its coverage at 10.2%.

TABLE 5
Lexical coverage of STWL and GSL on Science Textbook Corpus

Corpus	Coverage of the STWL	Coverage of the GSL	Total Coverage of STWL and GSL
Biology Subcorpus	14.4	68.9	83.3
Chemistry Subcorpus	15.9	67.9	83.8
Physics Subcorpus	10.2	79.6	89.8
Engineering Subcorpus	13.5	72.6	86.1
Entire Corpus	13.4	72.3	85.7

Although the STWL varies in the coverage of the subcorpora in the Science Textbook Corpus, it still provides minimum corpus coverage of 10.2% (physics subcorpus) and an average of 13.4% of all the running words in the Textbook Science Corpus. This coverage is comparable to other academic words lists. The AWL (Coxhead, 2000) covered 10.0% of the total words in an academic corpus, the Medical Academic Word List accounted for 12.2% of the tokens in the medical research articles (Wang, Liang, & Ge, 2008), and the Engineering English Word List (Hsu, 2014) covered 14.3% of the total words in engineering textbooks. All of these lists offer good coverage to students who use them, as the lexical items from the lists appear at least ten times per one hundred words in the texts that they were intended for.

The following passage was randomly selected from one of the biology textbooks (Alberts et al., 2008) in the corpus to give a general idea of the academic words used in such texts. The words included in the STWL are underlined and bolded:

> All **cells** are enclosed in a plasma membrane across which nutrients and waste materials must pass however, at least one other **feature** of **cells** that is universal: each one is enclosed by a membrane - the plasma membrane. This container acts as a **selective** barrier that **enables** the **cell** to **concentrate** nutrients gathered from its **environment** and retain the products it synthesizes for its own use, while excreting its waste products. Without a plasma membrane, the **cell** could not **maintain** its integrity as a **coordinated** **chemical** system.
> The **molecules** forming this membrane have the simple physic **chemical** property of being amphiphilic that is, **consisting** of one part that is hydrophobic (water **insoluble**) and another part that is hydrophilic (water **soluble**). Such **molecules** placed in water aggregate spontaneously, arranging their hydrophobic portions to be as much in **contact** with one another as possible to hide them from the water, while keeping their hydrophilic portions **exposed**. Amphiphilic **molecules** of **appropriate** shape, such as the phospholipid **molecules** that comprise most of the plasma membrane,

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spontaneously aggregate in water to form a bilayer that **creates** small closed vesicles. The **phenomenon** can be demonstrated in a test tube by simply mixing phospholipids and water together; under **appropriate** conditions, small vesicles form whose aqueous contents are **isolated** from the external **medium** (p. 9).

Of the 214 words in the passage, 28 belonged to the STWL. The text coverage of the STWL was 14.0%. This was consistent with the results as shown in Table 4.

To establish whether the 309-word family STWL was truly an academic science word list rather than a general word list, it was tested against a general word corpus and a science word corpus. The general corpus was the Brown corpus which consisted of 1,000,000 words of written English. The content of the Brown corpus was taken from 500 texts ranging in genres from humor and fiction to religion and hobbies. It was also compared against another science corpus of 1,761,380 individual tokens. That corpus consisted of fourteen subject areas ranging from agricultural and horticultural science to engineering and technology, and physics. The words used in the science corpus were collected from academic journals, university textbooks, and laboratory manuals (Coxhead & Hirsh, 2007). If the coverage of the STWL in a general corpus is lower than its coverage in an academic science corpus, it would suggest that the STWL is not a list of general purpose words, but rather a list of academic science words.

The STWL covered only 3.2% of the tokens in the Brown corpus as opposed to its lexical coverage of 8% of the science corpus. This marked difference suggests that the STWL is a list of words that are used far more frequently in the science disciplines than in general English. Even more importantly, the coverage of the STWL in the science textbook corpus of 13.4% is more than 5% higher in the general science corpus created by Coxhead and Hirsh (2007), suggesting that the STWL is a list of words specific to the science texts it was intended for.

To sum up, the STWL, having been compiled directly from target texts to cater to student needs, contains the most commonly used words traversing the subfields of the science and engineering domain at the institution it is intended for. Science majors encounter these words more often since different science specialist groups share them. Assuming these students already have some mastery of the GLS, their prior vocabulary knowledge supplemented with the STWL may provide a strong foundation for understanding the textbooks recommended in the university.

Word List Comparisons

In answering the second research question, two wordlists were chosen for comparison against the STWL. The first, the 570-headword Academic Word List (AWL) (Coxhead, 2000), was selected as it is a general academic word list, and, as can be seen by the many textbooks, webpages and research articles dedicated to it, is one of the most well-known and widely-used academic word lists (Coxhead, 2011). The second, the science word list of 318 headwords compiled by Coxhead and Hirsh (2007), is more technical in nature, does not contain any words from the AWL, and like the STWL, was created specifically with science majors in mind.

Before the results of the comparison, it should be noted that a number of words from both the AWL and the science word list can be found in the 309 STWL. Of the 309 word families in the STWL, 127 (41%) overlap with 570 word families in the AWL. This is not surprising, as there are a number of “lexical items that occur frequently and uniformly across a wide range of academic material” (Coxhead, 2000, p. 218). This means word families such as *affect, equation, hypothesis*, and *appropriate* can be found in both the AWL and STWL, as well as in a wide variety of other academic texts across various disciplines. There were 74 (24%) families in the STWL that overlapped with Coxhead and Hirsh’s 318-word families’ science word list. This overlap of the STWL and the science word list can be attributed to a lexicon relating specifically to the sciences. This resulted in word families such as *atom, microscope, species*, and *hydrogen* to be found in both lists.

Because all three word lists were created with the intention of assisting undergraduate students with comprehending textbooks used in a university, and a number of lexical items can be traced back to more than one word list, it would be of interest to find which list can give the best coverage of the Science Textbook Corpus. The results of the coverage of each word list can be found in Table 6.

TABLE 6
Lexical coverage of STWL, AWL and Science Word List on Science Textbook Corpus

Corpus	Coverage of the STWL	Coverage of the AWL	Coverage of the Science Word List
Biology Subcorpus	14.4	9.6	9.0
Chemistry Subcorpus	15.9	9.8	8.0
Physics Subcorpus	10.2	7.0	4.8
Engineering Subcorpus	13.5	10.1	4.9
Entire Corpus	13.4	9.0	6.7

The AWL coverage of the tokens in the Science Textbook Corpus was 9.0%. This is comparable to the 9.3% coverage reported by Hyland and Tse (2007) in their science corpus, and the 9.1% coverage of running words reported by Coxhead (2000) in her science based corpus. However, the 9.0% AWL coverage of the Science Textbook Corpus is 4.4% lower than the 13.4% coverage of the corpus by the STWL. Furthermore, it was found that the AWL could not outperform the STWL in any sub-section of the corpus. The highest coverage of the AWL against the Science Textbook Corpus was 10.1%, which was found in the Engineering subcorpus; however, the STWL coverage of the same subcorpus was 3.4% higher. The higher coverage of the STWL is encouraging given that the STWL is 261 word families smaller than the AWL. Students only need to learn 309 word families as opposed to 570 for an approximately 4.0% higher coverage on the scientific textbooks recommended for undergraduates at the researchers' university.

The explanation for the better coverage on fewer words stems from the reading material that was used to create each. The STWL was created solely from the discipline of science. The material was limited to texts from Biology, Chemistry, Physics, and Engineering textbooks. Coxhead's AWL, however, draws from a wide variety of texts from four different disciplines (arts, commerce, law and science). On top of this, texts from the subject of Engineering were excluded from the science subcorpus (Coxhead, 2000). Because the STWL did not include vocabulary from subjects such as sociology, accounting, and marketing, but focused only on the lexica found in the science textbooks, it could offer a better coverage on fewer words.

The overall coverage of the Science Textbook Corpus using the science word list (Coxhead & Hirsh, 2007) was 6.7%. This was approximately 3% higher than the coverage of the running words of the fourteen science subject areas in Coxhead and Hirsh's (2007) corpus. This percentage, however, is more than 2% lower than the AWL, and as the overall coverage using the STWL was 13.4%, the science word list is 50% lower than that of the STWL. The science word list's coverage of the Engineering subcorpus was 4.9%, much lower than the 13.5% text coverage of the STWL for the same subcorpus. Its highest coverage was found in the Biology subcorpus at 9.0%, yet that was still 5.5% lower than that of the STWL. As with the AWL, this science word list did not perform better in any sub-section of the corpus when compared to the STWL.

The relatively low 6.7% coverage of the science word list (Coxhead & Hirsh, 2007) on the Science Textbook Corpus stems from the technical focus that the science word list has. The Coxhead and Hirsh science word list was created to supplement the AWL which means no vocabulary items from the AWL were included in the science word list. Because words from the AWL and STWL overlap (40% or 127-word families), a relatively large portion of the 13.4% STWL coverage of the Science Textbook Corpus can be credited to vocabulary from the AWL. The science word list, which excludes all lexica from the AWL, thereby provides lower coverage of the Science Textbook Corpus compiled by the researchers.

The results of the word list comparison leave instructors teaching science majors with three options. The first is to provide learners with a general academic word list such as Coxhead's (2000) 570-word Academic Word List (AWL). The AWL provided 9.0% coverage of the Textbook Science Corpus. However, using only the AWL will expose science majors to unnecessary vocabulary from other disciplines such as the arts, commerce and law. Another option is to give science students a pre-made wordlist created by other researchers related specifically to their major like Coxhead and Hirsh's (2007) science word list. This 318-word list provides a lower 6.7% coverage of the Science Textbook Corpus when compared to the 9.0% coverage of the AWL. However, as the science word list is meant to supplement the AWL, the coverage with both lists increases to 15.7%. The increase in coverage comes at a word cost, however, because the number words families to be studied grows to 888 words. The final alternative is for teachers to create word lists aimed more specifically for their science students from the material being studied or recommended in the university. This was the rationale behind the Science Textbook Word List (STWL). The 309 word families of the STWL accounted for 13.4% coverage of the Science Textbook Corpus. This is 4.4% better coverage than the AWL, and the STWL contains 261 fewer word families. Coxhead's AWL and the Coxhead and Hirsh's science word list combined cover 15.7% of the Textbook Science Corpus. This is 2.3% higher compared to the researchers' STWL, but instructors would need to present 579 more word families to their students to achieve this higher percentage.

To conclude, the usefulness of the STWL is evidenced by the 13.4% coverage on the Science Textbook Corpus. This textbook-specific word list outperforms both the general AWL (Coxhead, 2000) and the more specific science word list (Coxhead & Hirsh, 2007) on the same corpus created by the researchers. This confirms the argument by researchers (Hyland & Tse, 2007; Mundraya, 2006; Ward, 1999, 2009) that students studying specific disciplines would be better served with a list created from their area of specialization as opposed to a general academic word list (i.e., the AWL).

Conclusion

The goal of this study was to create a word list based on a corpus from textbooks that undergraduate science and engineering students are likely to encounter in their studies at the institution where the research was conducted. This list, the STWL, was then compared with other academic word lists such as the AWL, which is general in nature, and the pilot science word list, which is a science word list, but created for students at another university. We found the corpus-specific 309-word STWL covered 13.4% of the running words of our Science Textbook Corpus. This was approximately 4% higher than the 570-word AWL. This means with the STWL students can be given a word list that has 261 fewer words than the AWL, but still comprehend more of the text they are expected to read for their classes.

When the 318-word science word list was compared to the STWL, the coverage was 6% lower than the STWL. However, the science word list did not include any vocabulary from the AWL. If the science word list was combined with the AWL, the total coverage would be 15.7%, which would be 2.3% higher lexical coverage than the STWL. Unfortunately, this increase in coverage would come with increased vocabulary learning for the learners. The science word list and the AWL combine for a list of 888 head words, whereas the STWL only contains 309 headwords.

These results indicate that specific rather than general academic corpora can result in more efficient word lists that provide greater coverage with fewer words for the students to learn. By simply creating a word list from a more focused corpus, researchers and teachers can significantly reduce the vocabulary burden for their students.

Pedagogical Implications

The STWL has demonstrated that it is comprised of word families that are clearly associated with introductory science textbooks used in the university where the research was conducted. As such, the implications of this research may prove invaluable for syllabus designers, teachers, and the intended science majors alike. Firstly, because of its high frequency and range, the STWL can assist syllabus developers by acting as a reference to highlight or improve the presentation of these important word families when developing syllabi for the institution. Secondly, instead of choosing words to be taught based on intuition, instructors teaching the science majors in their classes will now be equipped with a

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manageable ready-to-use resource that provides direct access to the most frequently encountered academic words in science textbooks. Furthermore, as Hsu (2014) and Farrell (1990) noted, because the words are academic rather than technical in nature, instructors without science backgrounds can teach them. This means even those who teach English to science majors in General English classes can use the STWL. Teachers will now know not only which words should be taught as basic academic words for science majors, but can also use the STWL as a basis for various activities that will provide the learners with the opportunity to move beyond the word level. They will be able to help the learners understand the target words in a variety of contexts, such as collocations or larger lexical chunks (see Hirsh & Coxhead, 2009 for suggestions about implementing practical science-specific vocabulary activities in the classroom). Thirdly, after the teachers have directed the attention of the students to the essential academic words, the STWL can be used a tool for self-study. With clear and direct access to such a manageable word list, self-study can be done in a more efficient manner. The repeated exposure to the word families both in and out of class may then contribute the acquisition of these target words.

Finally, the STWL will improve students' confidence when they read their academic texts. The STWL with 309 word families accounts for 13.4% of the textbook corpus. Adding the 72.3% coverage of the GSL, the total coverage comes to 85.7%. When the STWL and the GSL are supplemented with technical vocabulary, which can account for 5-30% of the words in a text (Chung & Nation, 2003), plus words they already know such as proper nouns and abbreviations (Coxhead, 2000), learners may approach the 95% lexical coverage threshold needed for understanding a text as suggested by Laufer and Ravenhorst-Kalovski (2010). As such, the STWL can help undergraduate science students to comprehend enough of the recommended reading material in order to be successful in their specific discipline.

As a number of pedagogical implications have been discussed, the researchers believe that the STWL would prove beneficial as a tool at institutions where learners have just begun studying their general science courses. The STWL is a relatively short list of 309 word families compared to other word lists, yet it provides a 13.4% coverage on the science textbook corpus from which it was created. It also provided 8% coverage on another science corpus of approximately 1.7 million words and fourteen subject areas (Coxhead & Hirsh, 2007). Considering that the coverage of the AWL in Coxhead and Hirsh's (2007) science corpus and in Coxhead's (2000) academic science subcorpus was 8.96% and 9.1% respectively, the researchers would like to suggest that the shorter STWL could be used to help bridge the gap needed for science majors to transition from general English to the specific academic English required for their studies.

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Appendix A

Science Textbook Word List (listed by alphabetic order)

Headwords of the word family of the Science Textbook Word List

absorb
accelerate
accumulate
accurate
achieve
acid
activate
adapt
affect
aid
alter
alternative
analyse
angular
apparatus
approach
appropriate
approximate
area
assemble
assume
atmosphere
atom
attach
available
axis
biology
bond
cancer
carbon
catalyst
cell
channel
chapter
chemical
chemistry
circuit
code
coil
collision
combustion
communicate
complement
complex
component
compound
compute
concentrate
concept
conclude
condense
conduct
configure
consequent
conserve
consist
constant
construct
consume
contact
contrast
contribute
convention
convert
coordinate
core
correspond
couple
covalent
create
crystal
cycle
cylinder
data
defect
define
degrade
denote
dense
derive
design
detect
device
diagram
diameter
diffuse
dimension
displace
disrupt
dissolve
distinct
distribute
diverse
dominate
dynamic
electromagnetic
electron
electronic
element
emerge
emit
enable
encounter
energy

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ensure
environment
equation
equilibrium
equivalent
establish
estimate
eventual
evidence
evolve
expose
factor
feature
fibre
filament
final
fluid
flux
focus
formula
fossil
fraction
fragment
fuel
function
fundamental
gene
generate
generator
gradient
gravity
helix
hence
hybrid
hydrogen
hypothesis
identical
identify
illustrate
image
impact
indicate
individual
induce
induct
initial
input
insert
instance
insulate
integrate
intense
interact
intermediate
internal
involve
ion
isolate
junction
kinetic
label
laboratory
layer
lens
linear
link
locate
loop
magnet
magnitude
maintain
major
matrix
maximum
mechanism
medium
method
microscope
mirror
mobile
modify
mole
molecule
momentum
negative
network
neutral
neutron
nitrogen
normal
nuclear
nucleus
obtain
occupy
occur
optic
orbit
organic
orient
oscillate
output
overall
oxidation
oxide
oxygen
parallel
peak
percent
period
permeable
phase
phenomenon
physical
physics
planet
polar
pole
polymer
positive
potential

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precise
predict
previous
primary
principle
proceed
process
promote
proportion
proton
quantum
radiate
radioactive
radius
random
range
ratio
react
region
regulate
release
remove
require
research
resonance
response
reveal
reverse
role
rotate
saturate
section
segment
select
sequence
series
shaft
significant
similar
site
soluble
solute
source
species
specific
specify
sphere
spindle
stable
stimulate
strand
stress
structure
sufficient
sum
summary
switch
symmetry
target
technique
technology
terminal
theme
theory
thereby
thermal
thermodynamic
tissue
transfer
transform
transition
transmit
transport
undergo
uniform
unique
vary
vector
velocity
vibrate
viscous
volt
volume
wavelength
whereas