The Development of an Academic Collocation List for Undergraduate Mechanical Engineering Students

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Abstract
Acquiring collocations is widely considered to be essential in language learning. The question arises, however, as to what collocations merit students’ and teachers’ attention in ESP classes at a tertiary level. Thus, this corpus-based study aims to systematically develop an academic collocation list for undergraduate mechanical engineering students who learn English as a foreign language. To identify such a collocation list, the current study relied on a corpus-based approach and an expert-judged approach. The Sample Corpus of Mechanical Engineering containing 2.1 million words was compiled from required and supplementary textbook chapters, reading texts and research articles as specified in the course syllabi for the undergraduate program in Mechanical Engineering at a public university in Thailand. The development of the list involved five stages: 1) compilation of materials 2) creating a specialized corpus 3) extracting high-frequency node words and identifying lexical collocations 4) expert judgement; and 5) ordering the entries. These steps are in line with those proposed by Ackermann and Chen (2013) with some modifications. It is expected that this corpus-informed collocation list consisting of 282 entries will be highly useful for students majoring in Mechanical Engineering as well as ESP teachers and material developers. The complete list of collocations is provided in the appendix.

INTRODUCTION
According to Gardner and Davies (2013), academic vocabulary knowledge is essential for academic reading ability and also for learners’ academic success. Therefore, various lists of academic words were created: West’s (1953) General Service List (GSL), Xue and Nation’s (1984) University Word List (UWL), Coxhead’s (2000) Academic Word List (AWL), Gardner and Davies’ (2013) Academic Vocabulary List (AVL), Brezina and Gablasova’s (2013) New General Service List, to name a few. These lists have served as a useful source for vocabulary learning as they can be used directly by learners or help teachers and material developers when they produce in-house materials or design English for Academic Purposes (EAP) or English for Specific Purposes (ESP) courses. Coxhead (2000, p. 214) affirmed that “an academic word list should play a crucial role in setting vocabulary goals for language courses, guiding learners in their independent study, informing course and material designers in selecting texts and developing learning activities.” However, some educators (e.g., Chung & Nation, 2004) argue that a more specialized
word list, also known as a technical word list, is also necessary. To highlight the importance of a discipline-specific vocabulary list, Durrant (2009) argued that the vocabulary needs of learners in an academic discipline should be characteristically different from those in other disciplines. Thus, teachers have to deal with these student needs separately.

In order to investigate academic vocabulary that merits students’ attention, whether it be general or discipline-specific academic words, many studies have relied on a corpus-based approach. For instance, Coxhead’s (2000) Academic Word List (AWL), which consists of 570 word families, was obtained from a 3.5-million-word corpus of written academic text. Gardner and Davies (2013) explored the 120-million-word academic subcorpus of Corpus of Contemporary American English (COCA) to identify 500 words (or lemmas, to be precise) for the Academic Vocabulary List (AVL). In addition, in an attempt to identify specialized words in natural science disciplines, It-ngarm and Phoocharoensil (2019) created a 5.5-million-word corpus called the Science Academic Journal (SAJ) Corpus and extracted 432 word families that were frequently found. The following section will discuss reasons why corpora have been widely used among researchers who developed EAP and ESP word lists.

**Corpora as a tool for creating word or collocation lists**

It has been well-documented that corpora can be used to improve the way ESP teaching is approached (e.g., O’Keeffe & McCarthy, 2010; Mudraya, 2006; Coxhead, 2000). Toriida (2016, p.89) pointed out that “a corpus-based approach is a form of evidence-based language pedagogy that provides teachers with information to guide decisions regarding vocabulary teaching, learning, and testing.” To illustrate another benefit, McEnery and Wilson (2001) maintained that corpora provided domain-specific materials for language learning, which meet the needs of ESP students. The use of corpora also allows researchers to compare the frequency of a set of vocabulary or word combinations in a particular field of study with that in other ‘more general’ reference corpora. That is why several studies have focused on developing corpus-based discipline-specific vocabulary lists. However, this line of research mostly focused on creating lists of individual words and most of them did not create the lists based on a curriculum of a discipline. The present study therefore aims to bridge this gap through focusing on technical collocations in Mechanical Engineering.

The aims of this study are:

1) to create a curriculum-based representative corpus of Mechanical Engineering which presents frequent discipline-specific collocations.
2) to develop a corpus-based Mechanical Engineering collocation list which is highly useful for undergraduate Mechanical Engineering students and ESP teachers.

**Significance of learning and acquiring collocations**

There are many reasons why the significance of collocations, also called word combinations, prefabricated chunks (or prefabs), phraseological units, multiword units, or formulaic sequences, has been well-acknowledged. First, according to Chon & Shin (2013), formulaic sequences
make up a large proportion of natives’ lexical knowledge. It is believed that collocational knowledge is defining markers of near-nativeness. So, in the L2 learning contexts, it is very important for learners to be able to comprehend and retrieve lexical items as in prefabricated chunks. This seems to be consistent with what McCarthy and O’Dell (2005) suggested in the introduction of their book: increasing collocational knowledge can help learners speak and write English more naturally and precisely. Those who would like to specialize in a particular academic field need to sharpen their skills in selecting an appropriate word that fits the context, and this entails an ability to use collocations properly. If learners use inappropriate collocations, they may sound unnatural or, in some cases, even incomprehensible to others. Despite this fact, Ackermann and Chen (2013) note that producing collocations is a huge challenge for learners partly because they usually rely on a limited number of collocations. Also, some learners tend to overuse some sequences they are familiar with and underuse some less frequent but strongly associated collocations (Chon & Shin, 2013). In terms of receptive skills, some learners seem to be unable to distinguish a pair of near-synonyms which, according to Biber and Conrad (1999), will be easier to recognize if they know the collocations of those words. Because of these problems, it would be pedagogically valuable to have a collocation list which could help learners expand their vocabulary knowledge and also assist ESP teachers in making well-informed decisions about which word combinations merit their attention during their class.

METHODOLOGY

Research procedure

In an attempt to develop a corpus-based collocation list, the methods proposed by Ackermann and Chen (2013) were used with some adjustments. This involved five steps: 1) compiling course syllabi and preparing materials for corpus 2) creating a specialized corpus 3) extracting high-frequency node words and identifying lexical collocations; and 4) expert judgement; and 5) ordering the entries. In this section, the construction of a specialized corpus, The Sample Corpus of Mechanical Engineering, is described in detail together with the collocation selection criteria. Then the list’s implications for teaching and for course material development will be discussed. Also, future research needs will be outlined.

Step 1: Compiling course syllabi and preparing materials for corpus

Twenty-three course syllabi of all subjects for the undergraduate program of Mechanical Engineering at a public university in Thailand in Academic Year 2019 were compiled and categorized into three sub-disciplines: 1) Fluid Mechanics and Thermodynamics, 2) Dynamics and Control, and 3) Solid Mechanics. To ensure the accuracy of classification, a full-time lecturer at the Department of Mechanical Engineering at the university assisted in classifying each subject into the three sub-disciplines. Since the study particularly focused on Mechanical Engineering, all general or basic subjects for engineering students, including non-Mechanical Engineering students, were excluded at this stage. These general subjects are, for instance, Engineering Drawing, Engineering Measurement, and Modern Computer-Based Manufacturing.
System. The required and supplementary textbooks, articles, and reading texts as specified in the course syllabi were subsequently compiled and saved in PDF formats so that they were compatible with LancsBox, which was a concordancer employed in the next step. To do this, a great deal of attention must be paid when the book chapters were selected. It is worth noting that all the compiled materials were a complete chapter or section in the books, and not excerpts. Furthermore, to exclude the materials irrelevant to Mechanical Engineering i.e. to ensure the corpus consists of representative texts, some sections of the books such as prefaces, contents, acknowledgements, author’s biography, indexes, references or bibliographies, and appendixes were removed manually during this stage.

**Step 2: Creating a specialized corpus**

In order to create a corpus with a balanced range of topics, the materials selected were under the three sub-disciplines of Mechanical Engineering with equal weight. This is the technique used by various previous studies on vocabulary lists (e.g., It-ngarm & Phoocharoensil, 2019). The number of tokens per sub-discipline and the total number of tokens of The Sample Corpus of Mechanical Engineering together with its percentage are provided in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Sub-disciplines of Mechanical Engineering</th>
<th>Number of tokens (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fluid mechanics and thermodynamics</td>
<td>705,167 (33.34%)</td>
</tr>
<tr>
<td>2. Dynamics and control</td>
<td>705,890 (33.38%)</td>
</tr>
<tr>
<td>3. Solid mechanics</td>
<td>703,907 (33.28%)</td>
</tr>
<tr>
<td><strong>Total Number of Tokens</strong></td>
<td><strong>2,114,964</strong></td>
</tr>
</tbody>
</table>

**Step 3: Extracting high-frequency node words and identifying lexical collocations**

**3.1 Concordancer**

LancsBox v.5.1.2, developed by Brezina, Weill-Tessier and McEnery (2020), was used because it is equipped with features for counting tokens, types, and lemmas, calculating frequency of words, and extracting collocations, which serve the purpose of the current study.

**3.2 Identifying high-frequency node words**

Since the collocation list was created based on the assumption that frequency should be an indicator of whether a word would be useful for learners and teachers (Ackermann & Chen, 2013; Coxhead, 2000; Mudraya, 2006; Valipouri & Nassaji, 2013), the first criteria for identifying node words was frequency. The identification started with using the Words function in LancsBox v.5.1.2 to extract 3,500 most frequent words. Then, the 3,500 words underwent a manual qualitative review to exclude the following types of words:
a. Numbers, abbreviations, acronyms (e.g., EOUT, ASME, ASTM, MOSFET), and non-words such as one-letter or two-letter words which can be a part of math formulas, measurement units (e.g., psia, kpa, amp), or variables in equations.

b. Proper names (e.g., American). However, it seems pretty common in the Mechanical Engineering field that some principles or concepts were named after influential engineers, physicists, or scientists, so it was decided that the proper names which are a part of well-established principles or concepts (and which occurred with high frequency) were kept.

c. Function words such as preposition, determiners, conjunctions, pronouns, modals, and question words. Thus, only content words were included.

During this stage, the words also went through manual lemmatization to group together the inflected forms of a word in the same word family. The form which occurred most frequently was selected as a node word for the next step. To illustrate how the manual lemmatization was performed, consider the following frequency outputs from LancsBox v.5.1.2.

Table 2
Sample frequency output of the ‘refrigerant’ word family

<table>
<thead>
<tr>
<th>Word form</th>
<th>Absolute frequency of a word form in the corpus</th>
</tr>
</thead>
<tbody>
<tr>
<td>refrigerant</td>
<td>203</td>
</tr>
<tr>
<td>refrigerated</td>
<td>54</td>
</tr>
<tr>
<td>refrigeration</td>
<td>171</td>
</tr>
<tr>
<td>refrigerator</td>
<td>186</td>
</tr>
<tr>
<td>refrigerators</td>
<td>46</td>
</tr>
</tbody>
</table>

In this case, it is obvious that, compared to the other word forms, ‘refrigerant’ is most frequently found in the corpus. Thus, ‘refrigerant’ was selected as a node word.

Table 3
Sample frequency output of the ‘rotate’ word family

<table>
<thead>
<tr>
<th>Word form</th>
<th>Absolute frequency of a word form in the corpus</th>
</tr>
</thead>
<tbody>
<tr>
<td>rotate</td>
<td>205</td>
</tr>
<tr>
<td>rotated</td>
<td>134</td>
</tr>
<tr>
<td>rotates</td>
<td>186</td>
</tr>
<tr>
<td>rotating</td>
<td>380</td>
</tr>
<tr>
<td>rotation</td>
<td>548</td>
</tr>
<tr>
<td>rotational</td>
<td>177</td>
</tr>
<tr>
<td>rotations</td>
<td>118</td>
</tr>
</tbody>
</table>
Considering the frequency output above, ‘rotation’ is much more frequent than the other word forms, so ‘rotation’ was selected as a node word.

Following the lemmatization, General Service List (West, 1953) and Academic Word List words (Coxhead, 2000) were excluded from the list using the Microsoft Excel software program. Another criterion set for the node word selection was the absolute frequency of occurrence of > or = 60. This criterion was applied so that the final list would not be too long and readily applicable in the classroom. In addition, this is to follow Coxhead’s (2000) AWL word selection criteria. In order for a word to be included in the AWL list, it must occur over 100 times in Academic Corpus containing 3.5 million tokens. Because The Sample Corpus of Mechanical Engineering contains 2.1 million tokens (2,114,964, to be precise), a word which occurred at least 60 times in the corpus was selected as a node word. In this step, a great number of high-frequency words were excluded and the resulting list was reduced to 379 node words.

### 3.3 Identifying lexical collocations

According to Hunston (2002, p. 68), “It [collocation] can be considered as the tendency of two words to co-occur, or as the tendency of one word to attract another.” Also, Hunston (2002) highlighted the importance of using a corpus to investigate collocations by arguing that “collocation may be observed informally in any instance of language, but it is more reliable to measure it statistically, and for this a corpus is essential” (p. 68). The node words obtained in Step 3.2 were used to extract the collocates. Below are the criteria for determining collocates for the study.

a. The word must be in the 3-word span on the right or left of the node words. This is because the range is not too far nor too close for each pair to co-occur.

b. The collocate must be a complete word, not a number, an abbreviation or an acronym.

c. Lexical collocations, not grammatical ones, were selected.

d. To take the association strength (or collocational strength) of each pair into account, the Mutual Information (MI) score of the pair must be > or = 3, which is the recommended score by Hunston (2002). Ackermann & Chen (2013) adopted this criterion as well. An MI-score “compares the actual co-occurrence of the two items with their expected co-occurrence if the words in the corpus used were to occur in totally random order. In other words, the MI-score measures the amount of non-randomness present when two words co-occur” (p. 71).

e. The threshold, or the minimum frequency of the collocation (i.e. the occurrence of each pair) is set to be > or = 5.

In an effort to extract the collocate of each node word which met all the criteria above, the GraphColl tool in LancsBox v.5.1.2 was used. After setting the word span, the Mutual Information (MI) score, and the threshold, the GraphColl tool identified the collocates of each node word and ranked them in the order of decreasing MI scores as illustrated in the table below.
Table 4
Collocate output of ‘amplitude’

<table>
<thead>
<tr>
<th>Position</th>
<th>Collocate</th>
<th>MI score</th>
<th>Frequency of collocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>linearity</td>
<td>11.71</td>
<td>16</td>
</tr>
<tr>
<td>L</td>
<td>modal</td>
<td>10.09</td>
<td>22</td>
</tr>
<tr>
<td>R</td>
<td>scaling</td>
<td>9.99</td>
<td>5</td>
</tr>
<tr>
<td>R</td>
<td>decay</td>
<td>9.90</td>
<td>5</td>
</tr>
<tr>
<td>R</td>
<td>sinusoidal</td>
<td>8.66</td>
<td>5</td>
</tr>
</tbody>
</table>

As seen in the table, the collocate with the highest MI score were ranked first, followed by that with the second highest MI score and so on. The collocate which occurred most frequently among the top five collocates were included in the list. Therefore, the selected collocate of ‘amplitude’ was ‘modal,’ the position of which was on the left of the node word. In case a pair co-occurs as frequently as another, a pair with the higher MI score was chosen.

Any word combinations which did not meet these criteria were eliminated. There were, however, a few cases in which the node words were excluded, but not because they did not meet the set criteria. Rather, it was because of other reasons which are worth mentioning here as it would be beneficial for future research on collocation lists. First, as shown by their statistic information, a few node words (e.g., coil and array) usually stand alone i.e. they rarely appear with any collocates and/or are often surrounded with function words. These kinds of words were excluded during this process. Second, pairs of words which were obviously irrelevant to Mechanical Engineering were put aside. They were, for instance, photo courtesy, mentioned earlier and downloaded (from a) website. Supposedly, these pairs of words were more related to giving credit to a photographic content provider, or to referring back to a previous section of the book, but not to Mechanical Engineering, which is the main focus of the current study. Thus, they were not included in the list. Finally, it is also noteworthy that when two node words, which met all the criteria discussed earlier (high frequency and high MI score) happened to collocate with each other, it was decided that the pair of words was presented in the list once. Such word combinations were, for example, combustion chamber, Newton’s law, free-body diagram, oxygen (and/or) nitrogen, radius (of) gyration, sleeve bolt, static friction, and Cartesian vector. This was the reason why the resulting list was reduced to 333 pairs of words.

Step 4: Expert judgement

According to Chung and Nation (2004, p. 252), “technical vocabulary is part of a system of subject knowledge. It could thus be identified by referring to specialists who have a good knowledge of the subject area.” In agreement with this statement, a panel of five experts in Mechanical Engineering with at least six years of teaching experience (average = 15.6 years) at the Department of Mechanical Engineering at a public university were requested to judge whether each pair of words in the potential list should be included in the final list or not. The purpose of the expert review was to find out if the entries, which satisfied the aforementioned quantitative criteria were really worth teaching from a pedagogical perspective (Ackermann
The panel experts were informed of the objective and scope of the study, and were provided with statistical information about each entry i.e. the absolute frequency of each node word, the MI-score of each pair, and the absolute frequency of each pair in the 2.1-million-word corpus. They were then requested to rate the possible collocations, using the four-level scales. Below are the labels for the four-point Likert scale which were used by Ackermann & Chen (2013) and were partially based on the guidelines about using a rating scale for technical word identification suggested by Chung and Nation (2004).

1 = definitely exclude  
2 = not sure, but tendency to exclude  
3 = not sure, but tendency to include  
4 = definitely include

The entries that were rated 1 or 2 by two of the five experts were removed from the list. During this process, the experts suggested that additional contexts should be added to some pairs of words so as to make the meanings much clearer. The researcher found the suggestion highly constructive and justified because the contexts would make the list even more readily applicable in classroom as well. Thus, coordinating conjunctions (i.e. and/or) or prepositions (e.g., of a, on) were added and put in parenthesis in order to prevent confusion when the list is used. Moreover, proper names were capitalized during this step.

**Step 5: Ordering the entries**

There are many ways to organize or order the entries in the list. While some researchers (Coxhead, 2000; Valipour & Nassaji, 2013) believed that the organization should be based on frequency, Thornbury (2002) argued for using high learnability (i.e. easy to learn) and teachability (i.e. easy to teach) to organize the list. The rationale behind this idea is teaching efficiency in classroom. In addition, Watson Todd (2017) proposed that opacity of words should be another consideration when sequencing the list. To help teachers make an informed decision on what words merit more attention in a classroom, it was recommended that opaque words be put at the top of the list, whereas more transparent words should be put at the bottom. He convincingly argued that it would be a good idea to devote limited classroom time to words whose meanings were opaque or difficult for students to understand on their own.

In ordering the entries for the present study, Coxhead’s frequency criterion was adopted and the collocation list (see the Appendix) was presented in decreasing order of frequency of the node words to facilitate teachers. Teachers can probably start from teaching the collocations which occurred more frequently first.

**RESULTS AND DISCUSSION**

After five stages of corpus analysis and manual qualitative refinement described earlier, the academic collocation list for undergraduate Mechanical Engineering students was developed. The final list consisted of 282 entries. Further investigation into the absolute frequencies of
the node words showed that the highest frequency was 2,831 and the lowest was 60 times in The Sample Corpus of Mechanical Engineering, which comprised 2.1 million tokens. The absolute frequencies of the pairs of words ranged from 677 to 5 times. Since the high-frequency node words were ranked first in the list, it is recommended that undergraduate Mechanical Engineering students and ESP teachers at the tertiary level focus more on these collocations than those ranked lower. Also, since the list contains a pair of words, as opposed to single words, it is hoped that when the students use this list to improve their vocabulary knowledge, they would also be constantly reminded of the importance of both structural and lexical meanings, which are two elements of the English language we need to truly understand when producing or comprehending the language.

Another possible application of the list is for ESP material developers. It would be highly beneficial for ESP learners if high-frequency collocations are incorporated in teaching and learning materials, or alternatively, in classroom activities. Because the list was also proved to be pedagogically valuable from Mechanical Engineering experts’ point of view, ESP material developers and teachers can rest assured that familiarizing students with these pairs of words would not be a wasteful use of time and resources. Rather, with this study, such instruction would be well-grounded.

Furthermore, this study has enhanced our understanding of how to develop a specific-discipline collocation list. Several observations will be discussed here. First of all, several words in General Service List developed by West in 1953 (e.g., flow, absolute, and contract) were found to be polysemous and some of their meanings could be more useful for Mechanical Engineering students than others. That is why the idea of focusing on opaque words proposed by Watson Todd (2017) was reasonable and those words merit students’ and teachers’ attention as well.

Second, during the process of excluding words from General Service List and Academic Word List, it was found that certain words may seem to come from the same word family as those in two lists. However, upon closer examination, they actually have very specific and technical meanings, and therefore deserved to be included in the list of selected node words. These interesting words include actuator, airflow, bandwidth, centerline, circuit, stainless, and static. At first, these words look like GSL words which are act, air, band, center, circle, stain, and state respectively. Also, at first glance words like analog, automobile, compensator, concentric, and projectile might look like AWL words including analogy, automatic, compensate, concentrate, and project, respectively.

Third, it should be noted that some word forms are more common in Mechanical Engineering than the others in the same word family. This linguistic evidence can be considered characteristic of technical English. The tables below can illustrate this point.
As seen in the tables above, reaction and reactions are found to occur much more frequently in the Sample Corpus of Mechanical Engineering than reactants, reacting, and react. As for the ‘result’ word family, result, results, and resultants appear a lot more frequently than resulting, resultants, and resulted. These findings could be useful for both ESP teachers and Mechanical Engineering students. Such findings can also serve as base for future research. In addition, while examining the list of word forms, it was brought to the researcher’s attention that oftentimes, nouns are most frequently found compared to other word forms. Take Tables 3, 5, and 6 above as examples. Nevertheless, further investigations are required to validate this point.

Limitation and future research

One limitation of the study lies in the fact that the materials compiled in the Sample Corpus of Mechanical Engineering were limited to textbook chapters, reading text, and research articles specified in the course syllabi only. It is recommended that future research explore other kinds of learning materials such as slides or lectures in order to gain more insight into pedagogically valuable ESP words or collocations.

CONCLUSION

This corpus-based collocation list can be applied in settings where the instruction focuses on improving ESP knowledge of undergraduate students. It equips teachers with vocabulary knowledge necessary for them to “speak the same language” as their ESP students. Based on
Corpus analysis and experts’ evaluation, this list can help teachers and students decide which sets of vocabulary or collocations should be prioritized and incorporated in learning materials. It is hoped that this list would be like a compass which helps navigate students through their journey of mastering ESP English as well as gaining expertise in Mechanical Engineering, and ultimately lead them to an academic success.

THE AUTHOR

Boonyakorn Siensanoh has been working as an English lecturer at Chulalongkorn University Language Institute for seven years. She completed her M.A. in English Linguistics at the Faculty of Arts, Chulalongkorn University. Her areas of research interests include vocabulary teaching strategies, L2 writing, collocations, and corpus linguistics.

REFERENCES


## Appendix

<table>
<thead>
<tr>
<th>No.</th>
<th>Pre-Collocate</th>
<th>Node words</th>
<th>Post-Collocate</th>
<th>Absolute frequency of node words</th>
</tr>
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<tr>
<td>1</td>
<td>angular</td>
<td>velocity</td>
<td></td>
<td>2831</td>
</tr>
<tr>
<td>2</td>
<td>exact</td>
<td>solution</td>
<td></td>
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<td>3</td>
<td></td>
<td>plane</td>
<td>symmetry</td>
<td>1624</td>
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<td>4</td>
<td>free-body</td>
<td>diagram</td>
<td></td>
<td>1597</td>
</tr>
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<td>5</td>
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<td>maintain</td>
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<td>assembled</td>
<td>matrix</td>
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<td>moments (of)</td>
<td>inertia</td>
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<td>magnitude</td>
<td>(and/or) direction</td>
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<td>consumption</td>
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<td>1042</td>
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<td>(and/or) vertical</td>
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