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Review research paper

CHEMISTRY VOCABULARY TEACHING: A SHORT GUIDE FOR ESP TEACHERS

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Abstract. *All those concerned with English language instruction would likely concur that "vocabulary is the Everest of a language" (Crystal, 2003). Indeed, the most fascinating and demanding activity in language acquisition is teaching and learning vocabulary. ESP teachers face a unique challenge: helping students who will work professionally in various fields, from natural sciences to humanities, understand and adopt the technical vocabulary of a particular area. In this brief overview, we will contribute to acquiring technical vocabulary in chemistry.*
Over the last seven decades, numerous authors have compiled word lists for various purposes, ranging from general English (General Service List, West, 1953) to university vocabulary (University Word List, Xue and Nation, 1984), academic needs (New Academic Word List, Coxhead, 2000), and even a word list specifically for chemistry students (Chemistry Academic Word List, Valipouri and Nassaji, 2013). While each list has its benefits and drawbacks, they should all be regarded as helpful tools for learning new vocabulary, whether for ESP or general English.
The technical vocabulary of the natural sciences, particularly chemistry, is generally composed of words of Greek and Latin origin that are widely accepted in many languages, aiding in the acquisition of technical vocabulary. In this paper, we suggest several options for teaching this vocabulary. These include the examples and sources of suitable materials based on identified needs, focusing on word family determination, and creating lexical chunks for chemistry students.

Key words: *ESP, chemistry vocabulary, word lists*

1. WORD LISTS

When talking about English vocabulary, a hundred-year analysis of its corpus has shown that only about 2000 words make up 70-95% of the text regardless of its source (Gilner, 2011), which resulted in the compilation of the General Service List (GSL) (West, 1954). It still represents an unrivalled list of words for general English usage. Various levels of vocabulary have been studied by many researchers, but the classification into four levels (high-frequency words, academic vocabulary, technical vocabulary, and low-frequency words) still seems unmatched (Nation, 2001). Guided by a similar idea, Xue and Nation compiled the University Word List of 836 words divided into 11 levels according to frequency of use, and a little later, the Academic Word List (AWL) of 570 words in 10 levels was established in the fields of arts, commerce, law, and science (Coxhead, 2000). Given that this vocabulary consists of common words for various academic fields, it can

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only be considered a unique set that is relevant to all. However, when we talk about technical vocabulary, it should be noted that it contains words that frequently appear in specialized texts but are almost non-existent outside of them.

In addition to those mentioned above, the Chemistry Academic Word List (CAWL) (Valipouri & Nassaji, 2013) was created for the field of chemistry, based on the abundance of chemistry articles dealing with analytical, inorganic, organic, and physical/theoretical chemistry. This list ranks 1400 units, including the headword and related word forms. Considering a limited corpus the list is compiled on, the word families do not always include all existing members. For example, the headword analyse gathers related forms and spelling variants – *analysed, analyser(s), analyse(s), analysing, analysis, analyze, analyzed, analyze(s), analyzing* – but does not include *analytic, analytical, and analyte(s)*. Besides appearing in CAWL, the word *analyse* is also found in AWL but not in GSL. Based on this, a useful task for students could be expanding the CAWL with words that do not appear on the list, but which students have encountered while learning and reading chemical texts, as in the example above.

Since CAWL is structured so that the most frequently used word is at the top, starting with the word use, it is interesting that the first word primarily associated with the field of chemistry – *acid* – is found only at the 31st position and the only chemical words the list includes up to the 100th position are *atom, crystal, polymer,* and *oxygen*. The list can also be analysed from the standpoint of their functionality and meaning specificity. Functionality would primarily gather grammatical words (e.g., *can, each, only, then,* etc.), while content words could be classified according to their meaning specificity into general (*result, observe, temperature, water,* etc.), scientific-general (*investigate, scheme, structure, obtain,* etc.), and chemistry-specific (*catalyse, fluorescent, nitrogen, organic,* etc.).

A study by Hoshino (2010) investigated which of the five types of word lists – synonyms, antonyms, categorical, thematic, and arbitrary – facilitated L2 vocabulary learning in a classroom setting. The study showed that the words in the categorical list were memorised more effectively than those in the other lists.

Thus, a useful method not only for acquiring technical words but also for practicing general vocabulary is establishing a sort of chemistry glossary that would be an integral part of the learning material. This glossary should be periodically reviewed and updated as needed – using the latest news from IUPAC (the International Union of Pure and Applied Chemistry). Specifically, in 2016, the discovery of elements 113, 115, 117, and 118 was confirmed, respectively named nihonium, moscovium, tennessine, and oganesson, which students should be aware of within English language classes. Moreover, their professional knowledge can be expanded based on facts presented during English classes – history, anecdotes, fun facts, etc.

2. GREEK AND LATIN WORDS

The very name of the English course for specific purposes suggests that the syllabus should be tailored to students' occupational domain, starting with technical vocabulary and collocations, but it should also include frequent phrasal verbs, fixed and semi-fixed expressions, and idioms in such a way that students find words in their natural co-occurrences and avoid common errors. In chemistry, non-English terms are widely applied, and students should be taught the abundance of Greek and Latin words – starting from the term *'chemistry'* itself (Greek: *khemeia*) and some basic chemical concepts of

Latin origin (*mole, molecule, valency, metal, equilibrium, solvent, acid, laboratory, radioactivity*, etc.), Greek prefixes in the names of chemical compounds (*mono*-(o)xide, *di-*, *tri-*, etc.), Greek suffixes in the names of compounds (amyl-*ase*, lip-*ase*, sulph-*ate*, carbon-*ate*, chlor-*ide*, phosph-*ite*, etc.), Latin names of certain chemical elements and their generally accepted corresponding symbols (*iron* – lat. *ferrate* (Fe), *copper* – lat. *cuprate* (Cu), *lead* – lat. *plumbate* (Pb), etc.), and sometimes we even encounter hybrids of Latin-Greek origin (*acidophil*). Furthermore, since the meanings of Greek and Latin words are permanently fixed and widely recognized in science – from perhaps unexpected (*part, major, lethal*, etc.) to recognizable Latin origin (*transmissible, polynucleate, succussation*, etc.) – so 'technical English has more of an international character than does ordinary English' (Nybakken, 1959).

In essence, words of Greek and Latin origin represent the most striking examples of technical words in chemistry. This is evident in even the most cursory glance at any abstract. However, technical vocabulary also encompasses numerous words that are used in extended science discourse, and there are many examples of polysemy as well. We will demonstrate this with an example from a scientific paper:

> *Biological phosphorus occurs almost exclusively as phosphate in the redox state of + V, although a few phosphonic (+ III) and phosphinic (+ I) acids are found as secondary metabolites or as constituents of phosphonolipids. Here we show that a culture of a lithoautotrophic bacterium purified from marine sediments in Venice can grow by anaerobic oxidation of phosphite (+ III) to phosphate (+ V) while simultaneously reducing sulphate to hydrogen sulphide. To our knowledge, this is the first description of a redox reaction involving phosphorus in microbial energy metabolism, an activity that might have operated on the early Earth and which could represent an ancient evolutionary trait. (Schink and Friedrich, 2000)*

Greek words	Origin	Meaning
phosphorus	phosphoros (φοσφόρος)	light-bearer
phosphate	phosphoros + -ate	salts or esters of acids
phosphonic	phosphoros + -ic	a chemical compound containing phosphorus
phosphinic	phosphoros + -inic	derived from phosphine
lithoautotrophic	lithos (λίθος) + auto (αὐτός) + trophic (τροφή)	stone + self + nutrition
anaerobic	an- (ἀν-) + aer (ἀήρ)	without + air
hydrogen	hydro (ὕδωρ) + -gen (γένος)	water + producing
metabolism	metabolē (μεταβολή)	change; transformation

Latin words	Origin	Meaning
biological	Greek: bios + Latin: -logia	life + study of
oxidation	oxidatio → oxydatum	oxide
bacterium	Greek: bakterion (βακτήριον)	rod; small stick
marine	mare → marinus	of the sea
sediments	sedere → sedimentum	sit; settle
sulphide	sulphur + -ide	indicating a binary compound; class of elements
reaction	re- + actio	again + action
evolutionary	evolvere → evolutio	unroll; unfold
culture	colere → cultura	culture

Moreover, not only nouns are of Greek or Latin origin. In this abstract, two-thirds out of nine verbs, including participles, originate from Latin (indirectly from French, e.g., *purificare → purifier → purify*), and only three have Germanic roots and have evolved into their current forms through Old English, as shown in the table:

Verbs	Origin	Meaning
occur	Latin: occurrere	ob- (toward) + currere (to run)
find	Germanic; OE: findan	find; discover; obtain
show	Germanic; OE: sceawian	look at; see
purify	Latin: purificare	purus (pure) + facere (to make)
grow	Germanic; OE: grówan	grow; increase
reduce	Latin: redūcere	re- (back) + ducere (to lead)
involve	Latin: involvěre	in- (into) + volvere (to roll)
operate	Latin: operārī	work; labour
represent	Latin: repraesentāre	re- (again) + praesentare (to present)

In addition, all the verbs in the table are also used outside the specialized domain, being common in everyday communication and retaining the same meaning. This simple example demonstrates the heavy technical vocabulary load in the field of chemistry, but it is highly likely that students have encountered many technical terms in their native language during previous learning, so much of it will not be new or unfamiliar to them. From that point of view, ‘the first language can be a facilitating factor, and not just an interfering factor’ (Brown, 2007).

What ESP teachers necessarily deal with is adopting classroom procedures and attaching purposes to them (Bruton, 2002). After considering the students’ level of knowledge and the purposes ESP teachers wish to achieve, mastering chemistry vocabulary should involve selecting appropriate classroom procedures to meet these goals.

3. Word Families

Based on definitions that can be taken from reputable dictionaries, one can perform a grammatical analysis and explain the word formation process of technical vocabulary, as well as general English vocabulary, highlighting the difference between content words and grammatical words, as in the following example:

Molar concentration (molarity)

- the strength of a solution, esp. the amount of dissolved substance in a given volume of solvent, usually expressed in moles per cubic metre or cubic decimetre (litre); (collinsdictionary.com)
- a measure of the number of moles in each liter of a liquid; (dictionary.cambridge.org)
- the amount of a substance in moles per litre of solution (oxfordreference.com) – the number of moles of a solute in a litre of solution (britannica.com)

(The content words convey the key concepts, they carry the meaning and specific information; The grammatical words connect these concepts and provide the necessary grammatical structure and meaning, clarifying the relationships between the content words.)

Content words	**Grammatical words**
Nouns: *strength, solution, amount, substance, volume, solvent, moles, metre, decimetre, litre, measure, number, liter, liquid, solute* **Adjectives (past participle)**: *dissolved, given* **Adjectives**: *cubic* **Verbs (past participle)**: *expressed*	**Articles**: *the, a* **Prepositions**: *of, in, per* **Conjunctions**: *or* **Adverbs**: *esp.* (abbreviation for *especially*), *usually* **Determiner**: *each*

Besides *strength*, *amount*, *substance*, *measure*, *number*, and the generally accepted units of measurement (*metre, decimetre, litre/liter*), these simple definitions also include the 'most chemical' of all the listed words – *solute* (N) and its derivations *solvent* (N) and *solution* (N). The definitions also serve as a good example for further expanding word families. In this case, we provide the following along with new definitions of meaning, which can also be visually represented using a spidergram or table:

- ***soluble* (Adj)** – capable of being dissolved in a solvent;
- ***solubility* (N) –** the ability of a substance to dissolve in a solvent;
- ***dissolve* (V) –** to go or cause to go into solution;
- ***dissolution* (N) –** the process of dissolving a solid substance into a solvent to form a solution;
- ***solvency* (N) –** the ability of a solvent to dissolve a solute;

The above abstract has shown how even in a short text, a large number of technical words derived from Greek and Latin can be found. In their study, some researchers attempted to achieve a more precise classification into technical and non-technical words by comparing corpora and found that a word had to occur at least 50 times more often in the technical text than in the comparison corpus to be classified as a technical term (Chung and Nation, 2004). It should be noted that specific technical vocabulary is proportionally much more prevalent in natural sciences, including chemistry, and their study revealed that even 88.4% of technical words in applied linguistics often appear in other uses of the language.

In an English for Chemistry textbook, technical words, in addition to being listed below the text with explanation or definition, can be further elucidated in the glossary, and highlighted in the text itself using bold or italic letters. This encourages visual memory as well, which is just one of the various mnemonic techniques applicable in foreign language learning. Additionally, spatial organization of notes (spidergrams, flowcharts, tables, etc.) and encouraging students to devise their own cognitive maps based on personal associations can be useful. From the once applied method of diligently writing words dozens of times, we have come to language learning applications that have minimized the use of a pen. Unfortunately? Or perhaps not.

4. Sources and Lexical Chunks

Instructions for using laboratory equipment – from glassware to devices – can also be very useful in acquiring technical vocabulary. In fact, students themselves can set tasks for each other to describe a piece of equipment or glassware from the laboratory (as often used *Florence flask*) or, based on the description, guess the name of the described item (e.g., *It is an item of lab glassware; It has a round body, a long neck, and most often a flat* *bottom; It is used as a container to hold liquids*, etc). Also, a description of a specific part of equipment or device can be requested (e.g., *centrifuge*), or the task can be set by providing a description and defining its purpose so that the item is guessed based on the given clues (e.g., *It is a device; It separates fluids, gases, or liquids of different densities, sizes or shapes under the influence of gravitational force; It contains a spinning vessel*, etc).

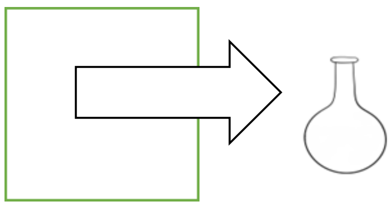
To become familiar with labels and warnings in the laboratory is of particular importance for students. Terminology related to substances that may be hazardous to human health must be acquired at the earliest stage of learning (*dangerous, hazardous, self-heating, fatal, toxic, skin sensitizer, eye damage, self-reactive*, etc), and special attention should be paid when the expected meaning is the opposite of the actual meaning of the word (*flammable/**in**flammable/**non**-flammable*). In these situations, the significance of knowing technical English exceeds general English proficiency, as it is directly related to workplace safety.

To acquire this 'technical' content, one can start with the simplest – visual – data that students can see in their chemical laboratories. Chemical substances in laboratories are always stored in containers that must be properly labelled with stickers. Among the data that must be included on these labels are Product name, Signal word (*'danger', 'warning', 'caution'*, etc), Pictograms, Hazard statement(s) (*irritant, flammable, corrosive*, etc), Precautionary statements, and Manufacturer name, address, and telephone number. Information on safe storage, handling, use, and disposal must also be provided, as well as the supplier's name. The date of production/acquisition and the expiration date are often required to be stated. At the very beginning of working in the laboratory, students should also become familiar with the labelling of hazardous waste. Chemical substance manufacturers provide a *Safety Data Sheet* along with the product – a document with detailed information on the physical and chemical properties of the product and emergency procedures.

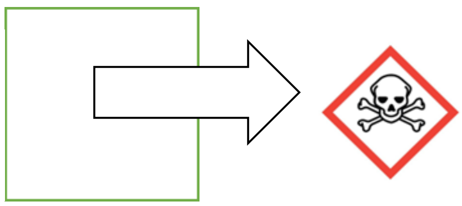
Visual material can also be helpful in teaching, both in the textbook itself and in presentations, suggested links on the Internet, and the like. For a change, students can be assigned the task of drawing a part of laboratory equipment or one of the symbols provided by the *Chemical Hazard Classification System*, whose terms and designators are provided through exercises in the textbook, such as:

Draw the following items:

a) Florence flask



b) Acute toxicity (pictogram)



The point is that expertise is gained and developed gradually, so that mundane tasks lead to more complex and demanding ones. Sometimes, however, even simple tasks are not so simple for students, such as when they are asked to describe a piece of laboratory glassware (e.g., *Florence flask* above) or a pictogram (a diamond-shape distinctive red border and white background and skull with crossbones inside).

So, instructions for using glassware and equipment in the laboratory, promotional materials from manufacturers, online advertisements for sales – all of these can also be useful materials for learning technical vocabulary. At the same time, some general grammar rules can be practiced, such as the passive voice, word order, indirect speech, etc. Here is an example of describing a piece of laboratory glassware:

Florence flask

1. It is intended for uniform heating, boiling, distillation, and ease of swirling.
2. It is available in a variety of glass thicknesses to accommodate various sorts of uses.
3. Its narrow neck can be easily locked with a cork.
4. The flask has a thin neck of 10cm in total length with a beaded rim. The inner diameter of the flask neck is 44mm, while the outer diameter measures 54mm.
5. Florence flasks are manufactured of high-quality GG17 borosilicate glass, which has a low coefficient of thermal expansion and can resist ordinary laboratory temperature changes.
(Vukićević Đorđević, 2024)

Students' research assignment could be: Who was the inventor of Florence flask and when was it invented? (Hints: Flat-bottomed Florence flask; produced by Kavalier Bohemia in Austria; believed to date from 1910-1930, etc.)

By using some nouns and verbs as examples, it can be shown how a word gains meaning only in context and specific discourse. For instance, *'bond'* in general English may refer to *'a close connection'*, but in chemistry, it is reduced to *'the force holding atoms together in a molecule'*. Similarly, while a *'compound sentence'* in linguistics consists of two or more independent clauses, in chemistry, *'compound'* refers to *'a substance that consists of two or more elements'* – complexity or a whole can be broken down into constituents. Analogy is present in numerous examples, and the context suggests that a familiar word is now used in its restricted meaning. Based on association and analogy, words should be taught in appropriate discourse and context.

Besides lexical items and grammatical structures, the importance of collocations should be emphasized, which involves placing vocabulary in a somewhat broader context and acquiring so-called 'chunks of language'. A multiple-choice exercise (I) could be a suitable instructional method, which can be replaced with no-hint gap-filling exercises (II) at the advanced level, as in the following examples:

(I) 1. The slurry of the silver nanoparticles powder had the ___________ toxicity.

a) harshest b) sharpest c) highest d) most powerful

2. The use of personal protective equipment is an important ___________ precaution.

a) safety b) security c) protection d) well-being

(II) 1. The label of this product warns about the ______________ toxicity of the product.

2. ____________________ means general activities that include wearing gloves, wearing eye protection, using equipment that is in good repair, cleaning up spills, access to a first aid kit, etc.

In the academic world, as well as in the context of vocational and occupational training, tasks based on real-world needs are the cornerstone of classroom analysis.

Recognizing the difficulties, the teacher will adjust the tasks to real needs by emphasizing the acquisition of vocabulary, phrases, and sentence structures that are truly needed by chemists. Learning by doing can be applied here through demonstrating experiments with elaboration in English, simple communication among students (*Please pass me...*, *Read from the instructions...*, *Measure the values...*), or between the instructor and students:

- What is H_2SO_4 in English? (*sulphuric acid*)
- Are there other names? (*dihydrogen sulphate, oil of vitriol, mattling acid*)
- Describe the acid using adjectives or phrases. (*colourless to brownish, very powerful, corrosive, oily, water-miscible, dense, dibasic, vigorous oxidizing agent, dehydrating agent, used in manufacturing batteries/dyes/paper/glue/ metals industries; present in volcanic gas; toxic fumes when heated*)

5. Conclusion

Finally, we can infer that teaching and learning vocabulary is the most interesting, yet also the most extensive, task in language learning. There are numerous available techniques, and the final outcome of the process in which both sides participate depends on the inventiveness of the teacher and the curiosity of the students. In the age of the Internet, state-of-the-art gadgets, and countless applications, it seems that this task is much easier today.

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