Abstract
Semantic verb types in chemistry research articles and their collocational structures have been analysed in order to determine the most highly co-occurring verbal patterns in a specific genre. In order to carry out this study, a selection of 25 articles from specialised journals has been processed with a concordance programme. Pedagogical implications regarding sense choice and the syntactical patterns they select in order to convey a specific sense are discussed in the paper. This paper analyses only the use of the thirty most frequent lexical verbs found in our corpus and is limited to the use of those verbs in the contexts where they have been found.

Key-words: corpus analysis; ESP; language teaching; materials design.

Resumo
Este estudo analisou tipos semânticos de verbos em artigos de pesquisa na área de química e suas estruturas colocacionais, com o objetivo de determinar os padrões verbais que co-ocorrem com mais frequência em um gênero específico. Para realizar este estudo, 25 artigos de periódicos especializados foram processados por um programa de concordância. Implicações pedagógicas relacionadas a escolha de sentido e os padrões sintáticos que selecionam para transmitir um determinado sentido são discutidos neste artigo. O artigo analisa apenas o uso dos 30 verbos lexicais mais frequentes encontrados no nosso corpus e limita-se ao uso desses verbos nos contextos em que foram encontrados.

Palavras-chave: análise de corpus; Inglês Instrumental; ensino de línguas; elaboração de materiais.
1. Introduction

The present study is concerned with the use of the 30 most frequent verbs appearing in articles dealing with technical ceramics. The creative power of verb collocational patterns and their implications in the production of ESP classroom activities is one of our main concerns. We believe that, as Jacobs (1991:35) has pointed out when he discusses knowledge sources for sense discrimination, “topic (...), the general context in which a word is used, is as important as the specific way it is used”. Studies like the ones carried out by Sinclair (1991), Biber, Conrad and Reppen (1994), Conrad (1999) or Cowie (1981), among many others, demonstrate how corpus analysis and collocational patterns provide useful information on particular aspects of language use. When a significant number of collocates of a word share one or more semantic features, it is possible to elaborate a sketch of the semantic behaviour and syntactic patterns that illustrate the meanings and use of a node or selected word.

2. Method

In this paper we have selected 25 research articles dealing with the topic of technical ceramics. Although it is a very small corpus, the subject has also been narrowed down to a specific research interest for Chemistry students in our university: technical ceramics. The results of this study therefore analyse a well-delimited area of research, an issue which is even more relevant due to the fact that most students will possibly work for ceramic companies in the future. A corpus was elaborated with articles belonging to the following research journals: American Ceramic Society Bulletin; Interceram. International Ceramic Review; Journal of the American Ceramic Society. The articles selected were published between 1996 and 1997. All articles were processed with a concordance programme (WordSmith Tools 2.0) and results from this analysis are organised and used to create theoretical information for classroom use and activities responding to the behaviour of words within this particular topic. The language scope covered here ranges from 1996 to 1997.
3. Results

The following 30 verbs were the most frequent in our corpus. Each verb was analysed in the context it appears so that collocational information could be retrieved. The verbs are grouped in four sections regarding semantic similarities or their use in a similar situation. Thus, group A contains verbs related to a mental process; group B includes verbs expressing some kind of comparison; group C lists verbs used to express that an event or a state is brought about; and finally verbs in group D refer to the manipulation of something. The information contained in this section may be used as theoretical information for the classroom. For each group, relevant collocates of the verbs are also discussed. The collocates considered here include both nouns and prepositions. Occasionally, adverbs and verbs also collocate significantly with the verbs analysed here (verbs appear as collocates to form verbal periphrases).

GROUP A) A number of the most frequent verbs refer to a mental process where the researcher finds out something about a method, material or process. These are the verbs calculate, consider, determine, show. Observe and study refer to the previous action that leads to the finding.

CALCULATE: The most frequent collocates of calculate are coefficients with the preposition from or with (can be calculated from / something is calculated with absorption and scattering coefficients), values, parameters, and the word (observed, non-corrected) transmittance:

(1) The absorption and scattering coefficients of turbid media could be calculated from observed transmittance

The words via/with/using introduce the way or method used in the calculation:

(2) difference was calculated using an equation which ...
(3) damage resistance parameter Rt was calculated via equation
**CONSIDER:** collocates with the words *method, results, model, details.*

(4) kinetic model may be **considered** for these heterogeneous
(5) results were **considered** sufficient in order to

The expression “was/were considered to be + participle/adjective” is preferred instead of a direct statement of the type “It/this was caused/influenced by ...” and expresses a more impersonal point of view or a lower degree of conviction:

(6) with clay content was **considered** to be caused mainly by iron
(7) these coefficients are **considered** to be influenced by size, distribution, ...
(8) was therefore **considered** to be negligible.

**DETERMINE:** The infinitive (expressing an end or finality) appears in periphrases of the type “calculated to determine”, “conducted to determine”, “used to determine”, etc. where a specific activity leads to a determination, or preceded by adjectives like “difficult to determine”, “necessary to determine”.

Words related to some kind of measure, like *value, parameters* or with the characteristics of some material, like *fracture, mass, viscosity, size* are the most frequent collocates of *determine*. The preposition *by* introduces a method:

(9) was then conducted to **determine** the effect of viscosity on
(10) it is often difficult to **determine** the exact values of the
(11) the parameters that **determine** the molecular size and
(12) phase chemistry were **determined** by X-ray fluorescence

**OBSERVE:** The most frequent collocates of *observe* are those related to the form or some negative result in the materials: *crystals, (micro)structures, grains, differences, impurities*. Words such as *values* and *phases* are also usual collocates:

(13) mullite crystals were **observed** by SEM. Such
(14) higher than the value **observed** for the crystalline phase
**SHOW:** *Show* differs from the previous verbs in that here the researcher somehow assists the reader to perceive something. Thus, words like *behaviour, tendency, trend, performance* collocate with *show* to indicate how something develops and what happens when a specific material or method is employed in an experiment:

(15) with wavelength *showed* almost the same tendency as  
(16) All binders *showed* the same performance

*Show* is followed by a long that-clause to introduce a hypothesis that has been demonstrated:

(17) the diagrams for the measurement of roughness *show* that after a rather rough grinding (used for roughing but not for overfinishing), the ceramic components have a high degree of settling, although they were obtained in ordinary conditions of compressing and sintering.

This verb collocates with *figure(s), data, tables,* etc. usually introduced by the preposition *in* and also appears with percentages:

(18) Figs. 9-13 *show* the microstructure of the  
(19) mullite gels *show* up to 35 % linear shrinkage and

**STUDY:** Objects collocating with *study* are words referring to the characteristics of the materials under examination or their reactions when applying certain techniques or carrying out experiments with them: *gravity, properties, thickness, characteristics, behaviour,* etc. Collocates for this verb also include words indicating contrast or comparison such as *relationship, the influence of.* The structure “*X was/were used to study Y*” is also frequent, and thus a method or a particular equipment (*viscometer, tests, thermogravimetric analysis*) may be used to study something:

(20) specific gravity was *studied.* A controlled viscosity was

**TEST:** The verb *test* collocates with *samples, systems, rate(s), viscosity* and is also found in the prepositional structure *was tested against* (which is a combination used in a domain-specific sense: contrast with, and so things are tested against a pattern or a model, or hypotheses are tested against previous experience or experiments):
Then, a combination of samples A and B were tested against a combination of samples B and C.

Samples were tested in accordance with the two.

Desired viscosity was tested. The results suggest that...

**GROUP B** Some verbs refer to differences or similarities. The verb *measure* expresses how the researcher tries to find out differences or similarities between two things or processes. *Improve* expresses how something is done to correct or make the differences more suitable. *Compare* (parameters, resistance, temperature, different materials, etc.), and *develop* would also belong to this type though they are less frequent.

**MEASURE:** The majority of the objects of *measure* allude to qualities and properties: toughness, absorption, thickness, shock resistance, transmittance and also to quantity: rates, time intervals, etc.:

Thickesses were measured and some of them were

Time intervals is measured as a squareroot function of

When the method of measurement is indicated, it is introduced by the words *by/with/using* or by *on* when it is an apparatus; adverbs or adverbials introduced by the preposition *at* are used to express how something is measured:

And prepared bodies measured by X-ray fluorescence

Constant was measured on a Hewleff Packard 419A

Damage thresholds measured at more than 9 J/cm² at

Samples are being measured simultaneously, it is not

**IMPROVE:** *Improve* collocates with words which are all understood as desirable conditions or ends: efficiency, quality, performance, properties, design, characteristics, behaviour, etc., that is, good performance, better casting rate, the best quality, and so on, even if the “good, better, best” is implicit in the sentence:

Requirement, but to improve efficiency of the systems

Should be used to improve plant performance. The

Fewer fines should improve the casting rate;
GROUP C) Another group refers to how the researcher or the characteristics of the material under examination do something to bring about an event or state, to make it possible: *make, achieve, allow, permit, cause, lead to*.

**ALLOW and PERMIT:** It is interesting to note the use of both *allow* and *permit*. *Allow* but not *permit* may be used in the passive voice followed by an infinitive. With the infinitive it implies that no external action affects the materials during the process:

(33) and the parts were *allowed* to cool for 30 s prior to
(34) The feedstock was *allowed* to mix until the torque

Both *allow* and *permit* are frequently used to express that things or experiments are carried out without any difficulty. The agent that collocates with *permit* or *allow* in this sense is usually formed by words or phrases like *analysis, comparison of..., collection of (much) data, measurements*:

(35) These data *allow* the absorption and saturation ...
(36) the better definition of the new method *permits* a better fit for the absorption and

the object may be words like *characterization, control, study* or words referring to positive results like *successful processing, optimization of process*:

(37) (a supply in) the contact container *permits* control of the water level

**ACHIEVE:** Collocates with objects (or subjects when the passive voice is selected) that denote a positive degree or quality: *full density, high precision/quality, uniformity, the desired powder-loading, success, improvement*, and also with words like *rate, parameters, (viscosity) target, phase*:

(38) powder was added to *achieve* the desired powder-loading
(39) full density was *achieved* in all cases. The high levels
(40) saturation phase was *achieved* at 3.1 min, and, in this
CAUSE: Usually collocates with negative words (substantial/greater proportional loss, multiple errors, worsening, damage, unreliable measurement, contamination, defective drying):

(41) of the processes that cause porous building material degradation

(42) Both differences probably were caused by a greater proportional loss of water

LEAD TO: is followed by nouns which are modified by adjectives indicating some kind of degree or mode: decreased, reduced, faster, high(er), significant, large, catastrophic, continuous, spontaneous. The nouns these adjectives modify usually refer to some kind of change in a material or a process: formation, cracks, transformation, breaking, increase, etc.:

(43) size which ultimately lead to cracks on the surface or in

(44) tools. This ultimately leads to a significant increase in the

(45) characteristics which lead to a decreased performance are

PREPARE: Prepare collocates with the prepositions from, with, at, through and with nouns like slip, slurry, etc.

(46) Suspensions were prepared at 50% solid added pieces of

(47) Composites can also be prepared from mullite ZrO2 glass

(48) of the slurries prepared under industrial conditions

(49) Slips were prepared using specific formulas and

PRODUCE: Produce is used to express the result of a process as an end or as an improvement or change in comparison to the previous state: a significant increase, satisfactory slips, an important quantity, coarser particles, sanitaryware, etc. The preposition by introduces a method or process:

(50) was too porous to produce satisfactory slips for actual

(51) reaction sintering produces coarser ZrO2 particles than

(52) Powder A is produced by the carbothermal reduction process

MAKE: has a causative sense in examples where the object is followed by an adjective (frequently followed by another verb in the to-infinitive form):
(53) These attributes make AIN an attractive material for
(54) of these parameters makes it possible to relate them

**GROUP D)** A different sense of *make* is to express that an agent manipulates something so that it is changed to some extent. Verbs belonging to this semantic type are: *make, heat, cool, quench, sinter, cast, dry, increase, decrease, reduce, mix, cut, mill*, etc. Only the most frequent are discussed here.

With the preposition *of* (indicating composition) or *from* (indicating source), *make* has the sense of producing by putting materials together, manufacture:

(55) components were made from this recycled feedstock
(56) The component is made of aluminous ceramics

*Make* collocates with *comparison, test, components, observations, test samples*, etc. and in the same sense (though not as frequent as *make*) we find the verb *perform* collocating with *tests, studies, method*:

(57) Comparison was made between the new and standard
(58) types of tests were made: Comparison between the new
(59) The tests were performed in an Instron machine with

**USE:** For *use*, something is manipulated to change or develop something else. Words like *method, tests, system* and words denoting different *materials* are the usual collocates functioning as the subject of *use*:

(60) The same method was used for the analysis of the

The gerund, *using*, frequently introduces a method, a machine, or an equation:

(61) were measured using the Hitachi Colour Analyzer

*Used* is followed by *to* introducing a specific activity (*compare, determine, describe, form, obtain, represent, study*). It is followed by *for* to indicate a purpose and is followed by a gerund or a noun and the preposition *of*:
(62) the Biot number is used to represent the heat transfer
(63) transducer was used to compare the energies applied
(64) the water can be used to control chemical and physical
(65) method was used for calculating the fractional
(66) casting is also used for the production of wash

The prepositional phrases in comparison, in (the) production (of), in X calculations, in this paper/study collocate with use and follow it:
(67) This is especially used in production of WC models. The
(68) strength was used in R calculations. The present

CAST: The verb cast collocates with bench casting, shank casting and different types of pressure, and with the words model(s), slip(s) functioning as an object:
(69) models cannot be cast at pressures higher than 10 bar
(70) if it has already been cast by bench or shanks casting
(71) casting can be cast by high-pressure casting with
(72) it is now possible to cast 8 different wash basin models

These collocations are also frequent in the nominalisation of the verb: cast/casting processes together with the collocations drain-cast, solid-cast, hollow cast (“Medium-pressure casting is also used for the ...”; “Shanks or battery casting is used in the production of ...”). When it is possible to use a verb to denote a process it is not usually employed in a verbal form and the preference is to use the nominalised form. Such is the case of casting, cooling, cutting, drying, heating, milling, mixing, packing, debinding, pressing, processing, scattering, sintering. Only those verbs where the verbal form is frequent are commented upon in this paper. Deverbal nouns indicating a process usually collocate with the prepositions before, during, in, after, by, and with the nouns phase, time, rate, speed (of), cycles, steps; moulds, models, slips, samples, and words that refer to the success of the process or lack of it (excessive, erroneous, successful, correct, incorrect, etc.).

DRY: collocates with sample, slip, moulds usually in the passive voice:
(73) The mixed slip was dried and shaped into discs (44 mm).
The noun *drying* indicating a process frequently co-occurs with negative collocates like: *defective, excessive, no, erroneous*. The noun most frequent collocations are: *spray-drying step/phases; spray-dried (powders)*.

**HEAT:** collocates with the preposition *in* to introduce the place where the heating process is carried out:

(74) on all sides, were **heated** in a vertical tubular furnace

The prepositions *to* and *at* introduce temperature and time: AT + °C/min + TO + °C:

(75) Y203 samples were **heated** at 2.5°C/min to 1835°C.

The noun appears in the collocations: *rapid heating, infrared heating, heating rates, cooling or heating* and prepositions like *during*.

**MIX:** The most frequent collocates of *mix* are: *constituents, feedstock, slip, powder*. The syntactic structure “mixed at (a solids loading of x vol % / 180rpm) at 120 °C” appears frequently in the co-text of *mix*:

(76) constituents are not **mixed** and stirred well, then the size
(77) The feedstock was **mixed** at 180 rpm at 120°C. Initially

**DECREASE and REDUCE:** In the present tense, *decrease* and *reduce* show preference for the use of different syntactic patterns. For *decrease* the thing that diminishes is the subject, for *reduce* it is the object: X decreases / Y reduces X.

(78) Green bulk density **decreases** as the chain length and
(79) ware and, thus, **reduce** the number of rejects. For

The most frequent collocates for *decrease* and *reduce* are words related to the quality of the materials or process: *performance, density, gravity, (impurity) levels, contamination, wear*:

(80) impurity levels can be **decreased**, which should lead to

**INCREASE:** Words preceding the verb *increase* are related to quantity or strength, weight, volume or value: *concentration, pressure, mass,*
density, size, value, number. The words following increase usually refer to some kind of process: production, powder loading, conductivity, reexpansion. Adverbs indicating degree may also follow the verb increase (e.g. significantly). When the starting and final point of the increase are quantified, prepositions (from – to), and the expression up to are used:

(81) grain size also increases from 3.11 to 3.25
(82) have continued to increase the thermal conductivity of
(83) with PVA binders increase significantly as

GROUP E) In a give and take process information is obtained or provided while problems are presented or “present themselves”.

OBTAIN: Collocates with words related to numerical information: results, data, coefficients, equations, information, etc. and words related to some material quality: density, absorption, etc.

(84) data can easily be obtained experimentally

Prepositional syntactic structures with by (indicating method) and from (indicating source) can be seen in examples like:

(85) The equations are obtained from simplification of the
(86) effects can be obtained by sintering at different

PRESENT: This verb collocates with: problems, difficulties, a few cases, cracks, etc. When used with the preposition in, it introduces figures, at is selected for meetings:

(87) (over 1.5 mm), even presenting cracks. In Table 2, the
(88) from alkoxide often presents problems due to the
(89) is based on a paper presented at the American Ceramic Society Convention
(90) is 0.994. The results presented in Table 4 and the

PROVIDE and REQUIRE: Provide collocates with some kind of data allowing a better understanding of a problem (an example, information, some understanding, an easy solution, accuracy):
(91) ensembles would provide more information as to the
or with words indicating some quality that is required (densification/density, strength, absorption coefficient, the required pressure):

(92) molecular weights provide higher green strength when
(93) processing, which provides molecular level homogeneity
(94) to approx. 1375 °C, providing sintering resistant pore materials

a common phrase is provided in solution X:

(95) Wacker had been provided in solution (50 wt%) by the

Require is used with in to indicate a stage or phase; with to and for to introduce an end:

(96) precise control is required in every production stage
(97) homogeneous mixing is required for consistent feedstock
(98) and research are required to compare the performance

Require is used in the passive voice when something has to be done to the subject (time, experience, conditions, a few castings) or is needed so that an aim is achieved:

(99) a few castings are required, seems to be the biggest

REPRESENT: The verb represent is used to exhibit or perform different kinds of (image) information provided in the articles. It is used to show a thing, to depict some kind of data, to exemplify, and collocates with figure, table, data, parameter and slope, peak, broken lines, curves, etc.:

(100) and broken lines represent body (C) with 0.96 mm and
(101) and R parameter is represented in Fig. 1 which shows
(102) Solid lines represent transmittance curves of body A
4. Conclusion and pedagogical implications

a) The data collected from the examples in our corpus may be used as background information/knowledge for teachers. This means that when students ask a question regarding the verbs we have analysed we are prepared to provide specific information regarding specialised texts or to include them in a lesson when we consider it interesting or necessary. By analysing specialised corpora our criteria for the selection of concepts to be covered in class improves considerably.

b) The collection of words from the corpus allows us to observe explicit rules for the use of, for instance, near synonyms or related words (heat vs. sinter; allow vs. permit; etc.). Many times the ESP teacher is unaware of the use of such words which may cause problems or doubts to our students. By the use of corpora these data become visible and the teacher/researcher is somehow forced or led to investigate the behaviour of particular words.

c) Semantic prosody may be included in specialised dictionaries, thus providing the student with appropriate information. We have seen how, for instance, the tendency is for a crack to be caused or something leads to cracks and in any case cracks will occur but will not be made and they do not appear either.

d) We have created our own classroom material based on the most frequent verbs and their patterns of use in ceramic research journals. We are not just explaining and working with a language feature in general, but with the language features which are recurrent in the specialised texts and which our students may run into. Following are some classroom activities based on the information obtained after our corpus analysis.
Example 1. – Complete the missing words using the clues:

In an experiment d_ _ _ are observed
information is obtained
pro_ _ ded
Values and parameters are det _ _ _ _ _ ed
repr_ _ nted
c_ l _ _ _ _ _ ed
via / using equations
obt _ _ _ ed
ob _ _ _ ed
shown
coefficients are co_ _ dered
and results are pres_ _ ted

Example 2. – Complete the following sentences using prepositions (preposition meaning and use can be explained in context and we may provide a number of examples for each use, trying not to make it just a “guessing” exercise for good memory):

1. Samples were heated __ 2.5ºC/min __ 1835ºC. (at, to)
2. Thermal conductivities could be further improved __ optimizing the sintering cycle. (by)
3. Parameter Rt was calculated ___ equation (1). (via)
4. Composites can also be prepared ____ mullite ZrO2 glass powder. (from)
5. The feedstock was mixed __ 180rpm __ 120ºC. (at, at)
6. etc.
Example 3. – The following words and phrases describe products/materials. Write each quality under the verb they may usually appear with. Some of them may appear under more than one verb:

- good quality
- substantial loss
- contamination
- unreliable measurement
- the desired quality
- damage
- cracks
- problems
- an improvement
- viscosity target
- defective drying
- uniformity
- impurities
- optimization of process

CAUSE  ALLOW  PERMIT  PRESENT  ACHIEVE  OBSERVE

_____  _____  _____  _____  _____  _____

_____  _____  _____  _____  _____  _____

etc.  ...  ...


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