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DESIGN OF A DICTIONARY TO HELP SCHOOL CHILDREN TO UNDERSTAND BASIC MATHEMATICAL CONCEPTS

Abstract This paper presents the decisions behind the design of a maths dictionary for primary school children. We are aware that there has been a considerable problem regarding Mexican children's performance in maths dragging on for a long time, and far from getting better, it is getting worse. One of the probable causes seems to be the lack of coordination between maths textbooks and teaching methods. Most maths textbooks used in primary schools include lots of activities and problem-solving techniques, but hardly any conceptual information in the form of definitions or explanations. Consequently, many children learn to do things, but have difficulty understanding mathematical concepts and applying them in different contexts. To help solve this problem, at least partially, the project of the dictionary was launched aiming at helping children to grasp and understand maths concepts learned during those first six years of their formal education. The dictionary is a corpus-based terminographical product whose macrostructure, microstructure, typography, and additional information were specifically designed to help children understand mathematical concepts.

Keywords children's specialised lexicography; corpus-based terminography; mathematical terms; children's vocabulary; conceptualisation

1. Introduction

Form an early age, children start to acquire mathematical and geometrical concepts, such as those of basic shapes, quantities, distance, and to make comparisons between objects[1] within their everyday life activities. They will refine these concepts when they begin their primary school education which, in turn, will prepare them to learn more abstract concepts in a formal way. For Cabré (1993, pp. 222 f.) the main differences between terms and general language words (GLW) are: a) terms are explicitly learned while GLW are spontaneously learned in everyday life experiences; b) terms have a referential function, GLW mainly have a conative, an emotive or a phatic function; c) terms are used in one or more specific domains of knowledge, GLW are used in everyday life situations; d) terms are used in formal communicative situations, GLW are used in less formal communicative situations; e) terms are used in a professional or scientific discourse, GLW are used in general discourse; and f) terms are used by specialists, GLW are used by every speaker of a language.

Pozzi (2016, pp. 112 f.) expresses some concern in relation to the way in which linguistic units designating basic mathematical concepts are considered in practice: Are these terms or GLW? The answer depends on who is replying to the question. For an educated adult or a specialist these linguistic units probably are general language words, but for children who must learn them, teachers who must teach them, textbook authors, education policy makers and others working in related fields, these are terms, since they satisfy all but one (children are no specialists) of Cabré's criteria for being terms. Because of the lack of consensus on their nature or perhaps because these units share most of their characteristics with both

[1] Such as "*a* is bigger than *b*", "*a* is smaller than *b*", "*a* is equal to *b*", "*a* and *b* are different".

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GLW and terms, the maths vocabulary learned by children in primary school has not received a lot of attention from terminologists and linguists alike. For the purpose of this project, linguistic units representing mathematical concepts at the lowest level of specialisation are assumed to be terms.

But one thing is for certain: from that age on, children will eagerly learn and like maths depending on how well they understand and make their own these first concepts taught at school. Thus, the great importance of acquiring both concepts and terms right from the time of their first encounter.

2. Background

After several years of planning, discussing, and arguing about pros and cons, some sixty odd years ago, Barriga (2022) tells us, Mexico made a major political move to provide "a public, universal and free education to open the paths to the liberating hope that knowledge can offer". In practical terms, this meant a standardised national curriculum, and a set of free-for-all textbooks (LTG)[2] for each child attending primary school whether urban or rural, public or private. This, in principle, was an extraordinary step to guarantee the same education for every child. However, from the very first edition, the LTG have had a high degree of controversy in almost every aspect, including the quality of their content, the constant changes, and other factors that have affected children's learning. For teachers, in turn, it has not been easy either, since, for every new edition they have had to face the confusion of constant and abrupt changes in approach and terminology, and many teachers have not been able to implement those changes in a satisfactory way.

The last few editions of maths textbooks have promoted the constructivist approach in which, following Piaget's (1967) ideas, children are expected to discover principles and construct their own understanding of concepts based on observation and on "doing things". Vygotsky's (1978) idea of "knowledge is constructed in a social context before it is acquired" has also been implemented. According to Pozzi (2016, p. 113), this change of approach has had a considerable effect on the teacher-children relationship in the classroom and on the content and presentation of textbooks. Teachers are expected to provide the appropriate guidance and environment to students so that they can make their own observations and produce their own mental constructs.

This new approach, although welcome in principle, has not proved effective for several reasons, among which, in my opinion, the following three stand out:

- Teachers were not offered compulsory training on the constructivist approach to teaching and learning; some of them are still oblivious to these changes.
- Although textbooks follow the constructivist approach, most schools do not conduct teacher assessment to ensure they provide the necessary guidance to students to help them conceptualise and construct their own knowledge; consequently, there is an obvious incompatibility between teaching methods and textbooks.

[2] From its initials in Spanish, *libros de texto gratuito* (LTG).

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– Maths textbooks contain activities, exercises, illustrations, problems to be solved, etc., but hardly any explicit conceptual information in the form of definitions or explanations.

As a result, if children fail to understand what they are doing, they cannot conceptualise well and in turn, the following concepts they are supposed to learn, based on the ones they could not understand, will not be understood either. This process can go on and on … In this context, it is not surprising that many children do not like maths and cannot progress as well as they should.

Perhaps this lack of conceptual understanding could be one of the key factors for the disappointing result in the Programme for International Student Assessment (PISA) conducted by the Organisation for Economic Co-operation and Development (OECD) that measures the level of achievement of children aged 6 to15 years, in mathematics, science and reading skills. According to the latest PISA assessment (OECD, 2019): "In Mexico […] the mean score in PISA performance in science and mathematics is well below average". It came out in 64th place out of a total of 79 countries in maths, with a score of 409 points, 182 less than the highest of 591 obtained by China, and only 82 points ahead of the lowest of 325 obtained by the Dominican Republic. In addition, if we consider that, according to the International Monetary Fund (2021), Mexico is the world's 15th largest economy, these results are alarming from a social, educational, and even political and economic perspectives.

With this background in mind, I believe we can help children to improve their skills, to conceptualise and to acquire those very first mathematical concepts – and terms – that are the basis on which they will construct their own mathematical knowledge in the years to come, by strengthening their concept understanding once they have made initial observations and have had hands-on practice on a particular concept or set of related concepts. For this purpose, we decided to prepare a corpus-based specialised lexicographical product that is intended to complement – not substitute – the information provided in textbooks.

3. Design of the dictionary

3.1 Preliminary decisions

As in any lexicography/terminography project, the product's overall design and the methodology to be followed were defined based on the answers to the following three basic questions:

a) *Why is it needed?* To help primary school children to improve their understanding of basic mathematical concepts.

b) *Who will benefit from it?* Primary school children, teachers, parents, and anyone whose understanding of basic maths needs to be enhanced.

c) *What information will it provide and how this information will be presented?* By publishing a corpus-based *dictionary*[3] providing conceptual, linguistic, and practical information in a clear, interesting, and in an appropriate language for children.

[3] Strictly speaking, our product is not a proper dictionary, nor is it an encyclopaedia, but it is somewhere in between. We decided to call it *dictionary* because it is the simplest term.

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The *why?* and *for whom?* need no further explanation. It is the answer to the third question that accounts for the main decisions taken to implement the dictionary the way we did. And so, I now provide a succinct justification for these decisions.

Firstly, we had to admit that, although we had extensive experience in standard terminography work, we had none in children's specialised lexicography. Therefore, we had to study as many children's specialised dictionaries as we could get hold of, in Spanish, English, and French.[4] We immediately realised that writing for children is different from writing for teenagers and adults. So, we decided to conduct some user studies involving children as the dictionary's main target users.

Secondly, we designed a series of three user studies to determine: a) the degree of understanding of maths concepts, b) whether the children could illustrate the dictionary, and c) what was the most efficient way to write and present the definitions.

a) The study to determine the degree of understanding of maths concepts was performed in an informal way so that the children would feel at ease. All children,[5] from 1st to 6th grade, participated. We had a list of concepts they should have learned that year and asked who could explain one or more. Most concepts were explained in a satisfactory manner; however, it was always the same top of the class students who answered, those who are good at maths and enjoy the subject. To assess the overall situation, we went further ahead and asked each child if he or she could explain a given concept to the rest of the class. Here, the results varied a great deal. In average, two out of five admitted that they had difficulties understanding that concept and therefore, could not explain it; about 2 in 5 said they thought they understood the concept but were unable to explain it; only one in five understood the concept and could explain it.

b) In line with the current trend of presenting children's dictionaries illustrated by children (Estopà, 2021), we asked the three schools involved in the dictionary project whether the children could provide the illustrations. It was agreed that all 4th to 6th graders would participate, and it would be done during school hours. Children were randomly assigned three concepts they were already familiar with, together with their definitions and a simple picture or drawing, just to give them an idea of what was expected of them to produce, though they could illustrate the concept in whichever way they wanted. Unfortunately, these illustrations could not be used because they did not have the required quality. So, as a last resort, we decided to have them made by a professional illustrator.

c) It was evident from the beginning that, for the dictionary to succeed in its main objective, the most important data category we had to get right was the definition. To achieve this, once again, we designed a user study involving children of 4th and 6th grades. After analysing several models to define terms found in children's dictionaries, we selected the three most suitable and drafted a definition for twenty concepts for each school grade (4th and 6th) in each of the following models:

4 Children's dictionaries we took some ideas from are listed in the References section.

5 The user studies were carried out in three primary schools between 2018 and 2019: *Colegio Madrid*, a co-educational private school, each grade has four groups with an average of 30 pupils per group; *Colegio Oxford para niñas*, an all-girls private school, each grade has three groups with an average of 15 pupils per group; and *Colegio Oxford para niños*, an all-boys private school, each grade has three groups with an average of 15 pupils per group.

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- traditional intensional definition (superordinate concept followed by delimiting characteristics) written in words they were familiar with:

  parallel lines

  Lines that are the same distance apart no matter how long they are, and they never cross each other.

- definition introduced in context, in the style of the Collins Cobuild Dictionary (Sinclair 1995):

  parallel lines

  If two lines are **parallel**, they are the same distance apart from each other all the way along their length.

- List of essential characteristics, presented as a bulleted list, each one written as a short sentence:

  parallel lines

  - lines that stay the same distance apart along their whole length
  - they never cross
  - they can be curved or straight
  - they do not need to be the same length as each other

Although the content of each definition compared with the other two is very similar, the form in which each one is presented makes it easier or more difficult to grasp. To determine which model was preferred by the children, we gave each child a set of five concepts, selected at random from the twenty that had previously been defined in the three models. They had to select the order in which they found it easier to understand the definition and explain why. For both age groups the result was clear: they felt more comfortable and understood the definition better when it was presented to them as a bulleted list of characteristics written in short phrases closely followed by those presented in context. We used one or the other, depending on the nature of the concept being defined. Very few children selected the traditional intensional model for definitions in first place; therefore, we did not use it.

Once these three user studies were completed, we were able to decide the dictionary structure (macro- and microstructure) as well as its typographical design.

3.2 Macrostructure

3.2.1 The dictionary as a corpus-based project

It was clear from the beginning that the macrostructure of the dictionary should include every term representing a mathematical concept that children learn during their primary school years. To make sure all terms were identified, the dictionary had to be a corpus-oriented project.

The first step consisted in setting up an appropriate corpus. For that purpose, we had already built a larger multi-purpose annotated corpus of about 6 million tokens, the *Corpus of Basic Scientific texts in Mexican Spanish* (COCIEM), containing complete maths and science textbooks that fully cover the school curricula for students aged 6 to 18 years. For the primary maths dictionary, we extracted the subset of COCIEM containing all official maths and exercise textbooks, freely provided by the Ministry of Education for every child attending

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any public or private primary school. These were complemented with nine additional maths textbooks corresponding to the most widely available books used in private primary schools. This ***Co**rpus of **P**rimary **S**chool **Ma**ths **T**exts* (COPSMAT) was the starting point to obtain the base list of terms for the maths dictionary's macrostructure (Pozzi 2016). It has 375,142 tokens and 8,533 types. Since the maths corpus is a subset of COCIEM, the lexical and terminological markup was already in place. Most of the terms had already been identified and tagged as a result of the term extraction and validation processes applied to COCIEM. These processes are fully described in Cabrera-Diego et al. (2011) and Vivaldi et al. (2012).

3.2.2 Entry terms in the macrostructure

The final list of terms in the macrostructure of the dictionary was compiled according to the following criteria:

a) Only math terms were to be included, which was evident; however, to avoid the accidental inclusion of terms belonging to another discipline or science, it had to be explicitly stated.

b) Terms included should be statistically significant, i.e., occurred in COPSMAT with a frequency ≥ 3, and occurred in two or more textbooks. The decision to eliminate terms with frequency 1 or 2 was made together with the teachers who participated in the user studies. Their main point was that children learn by repetition, by going back to a particular topic as many times as necessary, and they also need to be able to relate a concept with similar ones, which usually cannot be done it the concept occurs once or twice only. We also eliminated terms occurring in just one textbook regardless of its frequency because it may be a term used by an individual author, but its use may not be extended.

c) Very basic maths terms considered general language words that were not automatically extracted (e.g., line, distance, time, area, plus, unit) were included manually. This was important because specialised dictionaries tend to leave out very general terms which are usually defined in general language dictionaries. In this case, it was necessary to include them because some of them represent the most basic concepts on which children will base their understanding of more complex ones in the future.

d) Incomplete term families, for example, the names of polygons (pentagon, hexagon, octagon, decagon) were completed (heptagon, nonagon). In cases such as this, we decided to include the complete family because it is likely that any or all these terms should come up in a lesson as part of an exercise or example. In addition, from the terminographical point of view, the dictionary is expected to include complete term families in accordance with good practice measures.

The final number of terms entries that constitute the macrostructure of the dictionary is 842 including synonyms, abbreviations, signs, and symbols. The entries are presented in alphabetical order.

3.2.3 Annexes containing useful and grouped data

After careful consideration, we decided to provide at the end of the dictionary an additional section containing useful information, in the form of tables, grouped data, conversion tables, formulae, 2D shapes, 3D objects, etc. The following list shows the title of each piece of information included:

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- 2-D curve shapes
- 3-D objects: prisms, pyramids, cylinder, cone
- Abbreviations
- Addition tables
- Angles
- Celsius to Fahrenheit conversion formulae
- Days of the week
- Decimal system
- Divisibility rules
- Equivalent fraction / decimal / percentage table
- Equivalent fractions
- Formulae to calculate the area of 2D shapes
- Formulae to calculate the area of 3D objects
- Formulae to calculate the perimeter of 2D shapes
- Mathematical signs and symbols
- Metric, imperial, and American units
- Months of the year
- Multiplication tables
- Number line
- Prime numbers to 200
- Principal monetary units
- Quadrilaterals
- Regular polygons
- Roman numerals
- Square and cube roots whose result is an integer number 1 to 10
- Squared and cubed numbers to 10
- Table showing volume – capacity – mass relationship
- The circle
- Transformations: rotation, translation, reflection
- Triangles
- Units of time

3.3 Microstructure

Doubtless, the microstructure is the most important part of dictionary design, as it establishes the relationship between the author and the end user. It will succeed in its primary

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objective if it satisfies the user's needs. Before starting the practical terminographical work, a decision had to be made on the theoretical framework we would adhere to and consequently, the methodology that would be followed to ensure the success of the dictionary.

3.3.1 Theoretical framework

Children have their first encounter with terminology when they start primary school. They should learn their first mathematical concepts together with their corresponding terms in such a way that they really grasp the concept and learn to use the term for life. If the concept is well understood, it will not be confused or forgotten, and whenever they learn a new concept based on the one they have already acquired, they will easily understand it.

Since the main motivation for the preparation of the dictionary was the specific needs of children to help them understand maths concepts, our theoretical starting point was the principle of appropriateness proposed by Cabré in her Communicative Theory of Terminology (1999, p. 137), by which she states that

> [...] each specific job adopts a strategy based on its subject matter, objectives, context, elements involved and available resources. The methodology, therefore, [...] adapts itself to the circumstances without contravening the principles; the methodological appropriateness is paramount.

Although conceived as a concept-oriented product, the dictionary also provides entries for synonyms to make it possible for the children to consult the dictionary by whichever term they need to look for. For the online edition this will be transparent to the user because all synonyms, variants, and abbreviations will automatically redirect the search to the main entry term record.

In this context, the microstructure of the dictionary was set to include the following broad data categories: a) term-related data, b) concept-related data, and c) practical information data.

3.3.2 Term-related data

Term-related data associated with the linguistic information are important because they provide the primary access to the dictionary through the entry term, which can be a single or a multiword term, in the form it usually occurs in running text. These include entry term, synonyms, variants, abbreviations, signs, and symbols. The part of speech (POS) information corresponding to each term and its synonyms, variants and abbreviations is also included.[6]

When an entry term has synonyms or abbreviations, each one will have its own separate entry in the dictionary, but it will refer the user to the main entry.[7] Spelling variants are treated as synonyms.

3.3.3 Concept-related data

As the main objective of the dictionary is to help children to understand mathematical concepts, we included more concept-related data than it is traditionally provided in children's

6 In line with this type of dictionaries, the POS of term entries is limited to nouns, adjectives and verbs.

7 This is true for the print edition, although it will not be necessary for the online version; however, it will still refer the user to the main entry term representing the concept in question.

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dictionaries. In addition to children-oriented definitions (see section 3.1), we included the following data categories: a) maths subdomain to which the concept belongs, b) how to obtain a quantity, c) illustration, d) cross references.

a) *Subdomain* refers to the maths branch in which the concept is used: numbers and number systems; arithmetic; algebra; geometry; probability, statistics, and graphs; general vocabulary.

b) *Quantity obtention* refers to those concepts representing a quantity that can be obtained by applying a formula, as in the case of area or volume, or by means of an algorithm like solving a simple equation, adding fractions, or finding the highest common factor of a set of integers.

c) *Illustration* which shows an instance of the abstract concept and, where applicable, another instance showing one or more real life objects where the concept is applied. Sometimes, it also includes accurate diagrams and graphics that help to visualise the concept.

d) C*ross references* indicate terms included in the dictionary that are closely related to the entry term that can help children to establish explicit relations between the concepts they represent.

3.3.4 Practical and interesting data

This set of data was added to help children go from the concept to its application and vice versa. In some cases, they know how to apply a formula to solve a problem but do not understand the underlying concept. In others, they think they understand the concept but cannot apply that knowledge to solve a related problem.

These data include examples of a) how the concept is applied, b) additional information (encyclopaedic or interesting data), c) example, and d) problem solved explaining step by step how it is done.

a) *Application* refers to how the concept can be applied in real-life situations and provides an example. This is an important data category as it allows children to establish the relation between the abstract concept and its use in real life or from an object to its abstraction in a mathematical concept. For example, it goes from the concept of 'sphere' to the object beach ball and vice versa, from real life objects to the abstraction and concept formation, and mathematical description, as in the case of a snail shell to 'spirals' and 'curve description'.

b) *Additional information* refers to any information that might be interesting or useful to the children, such as some kind of encyclopaedic information, associated historical events, different uses and applications, related curious data, etc.

c) *Example* shows the use of the term in context. The term is highlighted in a different colour.

d) *Problem solved,* where each step is explained, always starting with a statement of what is being asked[8], then explicitly state the data already provided in the text of the problem

[8] At the time when the user studies were being conducted, we realised that when asked to solve a problem many children could not even determine what the problem was and what they were supposed to find.

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followed by the formula or arithmetic operation needed to obtain the required result, repeating this process as many times as needed. At the end, the result is highlighted in red and starts with a statement that refers to the initial one.

3.4 Typographical design

Our purpose for presenting the information is to make the dictionary as interesting, appealing and as dynamic as possible in such a way that children would enjoy consulting it while at the same time, it is consistent and coherent. This is important because:

a) we want to engage the children and make them curious as to continue reading entries in addition to what they were originally looking for.

b) children sometimes perceive dictionaries as "instruments of punishment" when they behave badly and must copy several entries (a reason to dislike dictionaries in general), so we want to show them that dictionaries can open the door to learning interesting things and can also be fascinating.

To achieve this, we defined the following set of typographical specifications:

- The dictionary will be published in print form and the online version will be available later.
- There is a page per entry in the print edition.
- Pages do not have a fixed layout.
- Colour edition.
- Each data category is presented in specific colour, for example, the term is always written in blue, the definition in red, additional information in green, solved problem in black, and so on.
- Use of the largest font size for the available space.
- Easy to read font type.
- Illustrations may be placed anywhere suitable on the page.
- There is an illustration of the abstract concept and whenever convenient, one or more real-life objects depicting the application of the concept.

4. Concluding remarks

The final stages of the preparation were severely delayed for several reasons, amongst which the difficulties to find a professional illustrator to accommodate the project in times of Covid-19. Virtual meetings were the new normal, but we had to learn how to communicate the ideas for each illustration without the closeness of face-to-face explanations.

On the other side, there were additional user studies we wanted to carry out to evaluate the final dictionary before going to press. However, because of the time lapse, many children who had taken part in the previous studies had already finished primary school. And all schools were closed for the best part of a year and a half.

So, the status of the print version of the dictionary is "soon to be published". The online version will come out a year after the printed version.

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With the publication of this dictionary, we hope to achieve the following:

a) help as many children as possible to understand basic maths concepts,

b) facilitate the establishment of links between related concepts in a way that each child may structure his or her maths knowledge,

c) establish a link between abstract concepts and their application to real life through well-chosen examples and vice-versa,

d) help children to learn the general procedure to approach a maths problem and solve it in a satisfactory way, by dividing it into partial steps,

e) have access to interesting and appealing information connected with the term children are consulting,

f) enhance maths knowledge in combination with the corresponding textbook,

g) hopefully, by understanding the concepts they learn, children will like the subject and therefore make the understanding of maths easier and more enjoyable.

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