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A Diagnostic Tool for Speech Disorders based on NLP with Ontological Reasoning

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Abstract. This work presents the development of an ontology for speech disorders in children, in order to become a tool to support therapists for diagnosis and possible treatment. Speech disorders are classified using a taxonomy obtained from a speech disorders corpus previously conformed. Based on this taxonomy, the ontology, which structures and formalizes concepts defined by the main topic authors, is developed. The ontology's main classes represent the taxonomic classification of speech disorders, their etiological origin, symptoms, and signs of each disorder, assessment, and intervention strategies; it also represents patients as it instances. A transcription module is also used to make different pronunciation tests and to obtain more detail of the characteristics presented by each patient to make the diagnosis. The development of the tool and the transcription module is based on Natural Language Processing (NLP) and Information Retrieval (IR) techniques. The importance of an early detection and diagnosis of a speech disorder –which can have a social, economic and educational impact–, lies in the fact that the prognosis of the treatment depends on the cause of the disorder and on an opportune treatment.

Keywords: ontology, speech disorders, NLP, IR, transcription tool

1 Introduction

A speech disorder is the difficulty to produce or to create specific speech sounds to communicate. Causes could be as diverse as hearing loss, neurological disorders, brain injury, intellectual disability, or physical impairments such as cleft lip [1].

According to Global Disability Rights, 7.5% of the population in Mexico has some kind of disability (about 9.17 million people), and 4.87% of people with a disability has some type of speech disorder (0.45 million people). In kids and young people the speech disabilities are in some cases twice or four times higher than in adults [2]. Persons with disabilities experience worse socioeconomic outcomes and poverty than persons without disabilities [3].

Early detection and diagnosis of a speech disorder is important because of the social, economic and educative impact that such disorders have in the life of infants.

Information and Communication Technologies (ICT) are helpful in almost every step of the diagnosis and treatment of speech disorders in children to provide the right care.

Ontologies give an unambiguous and well defined structure for a clear and accurate representation of a big amount of data concerning a particular domain, in this case speech disorders, and, thus, becoming a tool for diagnosis. Ontologies are made up of two main components: classes and relations (see Fig. 1).

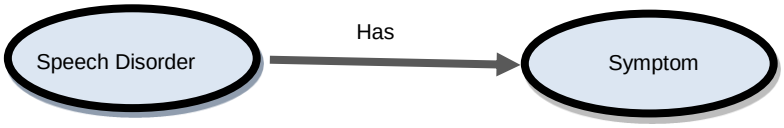

Fig. 1. Simple representation of the two main components in an ontology: classes and relations.

An ontology is proposed to organize and to look up information such as different disorders, characteristics of each disorder, therapy theory, taxonomy of the speech disorders, and some other helpful information for the therapist and patient, as well as the relations between all of them.

One of the earlier steps in the development of this ontology is the conformation of a Corpus, in this case of documents related to the domain of speech disorders. A Corpus is a large collection of texts. It is a body of written or spoken material upon which a linguistic analysis is based. Corpus analysis provide lexical information, morphosyntactic information, semantic information, and pragmatic information [4].

This document is organized as follows: section 2 presents the state of the art through the discussion of some works related to the subject of the present work. Section 3 talks about the corpus as a data source, and about the taxonomy. Section 4 explains the development of the ontology; subsections detail important parts for the ontology design and, at the same time, the implementation of the ontology in the Protégé software, as well as the use of its logical reasoner for the consistency tests, is shown. In Section 5 future work that can be conducted is mentioned. Finally, in Section 6, the current results and conclusions are outlined, followed by the references.

2 State of the Art

Within the field of speech and language several works that use Information and Communication Technologies (ICT) have been conducted, focusing on some specific ailments [5], on the automatic classification of the quality of pronunciation when treating some disorders [6], or, on an expert system for the initial assessment of children with possible speech disorders [7]. A so-called ecosystem of smart ICTs that include electronic medical record management, standardized vocabularies, a knowledge database, ontologies for concepts within the domain of speech and language, and expert systems focused on supporting speech and language pathologists, doctors, students, patients, and their relatives can also be found [8]. There are also tools for the formation of professionals in the field of speech disorders based on ontologies and e-learning, which support future language therapists in their training process, as well as in their development of practical abilities [9]. Regarding language therapies, a mobile app that integrates therapy activities for children and that uses colloquial language, as well as games from the state of Chiapas, has been developed [10]. There even are systems of

ontologies that cover several aspects of speech and language therapies, with initial assessment and patient profile, conducted tests, doctors and therapists catalog, list of disorders, speech and language fields, therapy, and tracking plans and exercises, among others, that use OpenEHR ontologies and constructs [11].

Regarding the building of the corpus, the classic main techniques have not varied a lot, and texts in a corpus need to be in electronic form. Thus, the fastest way to build a corpus is by gathering data that is already digitalized, or relying mainly in the transcription into electronic form of the audios, or documents [12].

The previous works have some constraints because some of them are not made for less specialized users, such as primary school teachers, or the taxonomies and ontologies are focused in a single or a very specific disorder or they are targeting only the part of repetition therapy leaving aside all the diagnosis process.

3 Corpus Building and Ontology Development

To build a Corpus, it is necessary to gather a big amount of documents relevant to speech disorders through a Web Crawler. Once a representative amount of those documents is obtained, they need to be pre-processed in several steps to clean up and standardize the data though algorithms like normalization and stemming. The purpose of building this corpus is to obtains a data source for the expanded taxonomy and validate the classes and subclasses in the ontology mainly.

3.1 Corpus Building

The building of a corpus is divided into two stages: design, and implementation. A good practice in the stage of design is to define what, ideally, the corpus would have in terms of the amount and the type of language, and then the parameters could be adjusted as the building goes along, keeping a careful record of what is in the corpus, so it can be added and amended later, and so that if others use the corpus they know what is in it [12].

In order to build a corpus there are a number of factors which need to be taken into consideration. These include size, balance, and representativeness. The main tool to gather the information to build a corpus is a Web crawler. A crawler can be defined as an Internet bot that browses the World Wide Web, typically with the purpose of Web indexing. This crawler is fed with some initial seed pages to start its task. At their core is an element of recursion. They must retrieve page contents from an URL, examine that page for another URL, and retrieve that page, *ad infinitum* [13]. To find documents relevant to the domain, and not just a list of links and random data contained into the seed page, it is necessary to establish a primary dictionary at the beginning of the crawling, and the retrieval of each document is conditioned to contain at least one of the terms from the dictionary. This dictionary or more properly a lexicon is made of some of the more meaningful words within the domain. Another way to complement the corpus is to include synonyms, hyponyms and hypernyms from the original terms to gather more documents [14].

Pre-processing the data in the corpus is the next step. This is done through several algorithms that normalize the texts contained in the corpus. Once all the data gathered into the corpus is normalized the next step in the process can be done.

Some data about the corpus is now presented in Table 1.

Table 1. Some outline data from the corpus.

Number of initial terms used in the gathering of documents.	15
Number of offline documents added to the corpus.	250
Number of documents obtained at the end of web crawling.	1097
Corpus size of plain text in bytes.	8,416,391

The taxonomy mentioned in the following subsection and also the advice of experts in the field was used to obtain the fifteen initial terms for the lexicon. Some of the terms and their respective synonyms, hyponyms and hypernyms are listed in Table 2.

Table 2. Some terms from lexicon and their related terms.

Hypernym(s)	Term	Synonym(s)	Hyponym(s)
Defect of speech	Dyslalia	Dysphasia.	----
Defect of speech	Dysarthria	Aphasia.	----
Verbalize	Dysphemia, Childhood-onset fluency disorder, Rhythm disorder.	Stammering, stuttering.	----

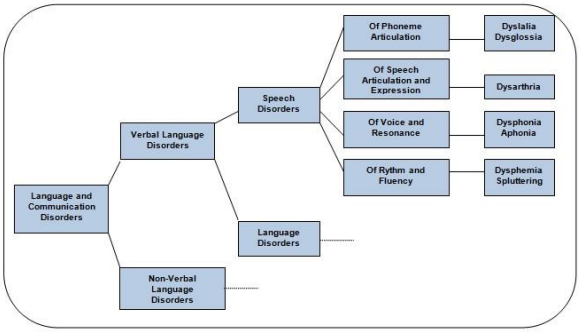

Fig. 2. Gallego and Gallardo's taxonomy of speech disorders.

3.2 Taxonomy Design

Starting with a taxonomy of speech disorders proposed by Gallego and Gallardo (see Fig. 2), and recovering data from the corpus, the next step is to expand the taxonomy and include all the speech disorders referred by the retrieved documents [15].

The ontology is just focusing in the speech disorders branch of the previous taxonomy, so this branch is expanded into more sub categories, and the ontology also integrates other taxonomies about speech disorder etiologies, therapy strategies, persons, and signs and symptoms; being all this information retrieved from the corpus

previously built by IR algorithms. Once the five different taxonomies are complete and integrated, the following step is the development of the ontology using those taxonomies as a base.

4 Ontology Development

First, the scenario in which the ontology is applicable has to be defined, followed by the generation of the so-called "competency questions" in natural language, whose objective is to determine the ontology reach. These questions and its corresponding answers are used to extract the main concepts, as well as their relations, properties, and axioms within the ontology. The formality of this method allows us to transform informal scenarios into computational models. The elements for the design are the following: taxonomy construction for the knowledge-base to be represented; attributes and relations within classes; and, rules and instance's attributes.

The use of ontologies to represent a knowledge-base within a certain domain has the purpose of facilitating the understanding of such domain, and to obtain better information on the subject. The relevant information about the speech disorders are the classification of each disorder with their own sub classifications to correctly classify the disorder presented by every patient, the signs and symptoms produced by each disorder –those are the clues the therapist should look for–, the etiology that could affect the course and results of the therapy, and the different parts of the therapy, first with an assessment strategy, and then with an intervention strategy led by the therapist. Once the scenario for the competence area of the ontology is defined, the set of taxonomies can be used to arrive to a definition of the ontology's classes (see Fig. 3) and the relations between them; a series of questions expected to be answered through querying the ontology is also defined. A formal definition is made for the classes and its attributes, as well as for the description of the ontology's relations and axioms.

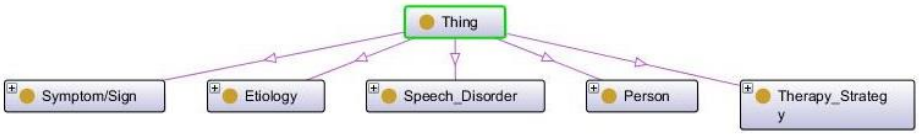

Fig. 3. Ontology's main classes.

4.1 Competency Questions

Competency questions are an important part in the ontology design steps because they allow to define the domain and scope of the ontology.

The proposed ontology looks for answers to questions like the following:

- Which is the most common speech disorder in children?
- Which are the symptoms of a speech disorder?
- How many types of speech disorder exist?
- What's the cause of a certain speech disorder?
- What's the therapy for a speech disorder?

- What's the dyslalia?
- At what age can a speech disorder be noticed?

The ontology knowledge base must be capable to answer such questions. At this phase the questions are presented in natural language.

4.2 Class Definition

The following entities are some that were found after an analysis of the scenario from the competency area (see Table 3). A mixed strategy was used (top-down and bottom-up) to identify the main concepts [16].

Table 3. Classes' definition.

Class	Definition
Speech_Disorder	This class contains the whole taxonomy of speech disorders.
Etiology	This class includes the taxonomy of the speech disorders' different causes.
Person	This class includes the different individuals that are diagnosed with (Patient) or diagnose a speech disorder (Therapist).
Symptom/Sign	Class including the different symptoms or signs that are presented by a patient with a speech disorder.
Therapy_Strategy	Class containing the two main parts of the therapy actions applied to patients.
Articulation_Disorder	Subclass of Speech_Disorder, consists in the difficulty to pronounce sounds.
Rythm_and_Fluency_Disorder	Subclass of Speech_Disorder, refers to an alteration in the speech rhythm.
Voice_and_Resonance_Disorder	Subclass of Speech_Disorder, is a voice alteration in the volume, tone or timbre.

The previous classes and subclasses can be seen in the following hierarchic diagram generated with the Protégé software [17] (see Fig. 4).

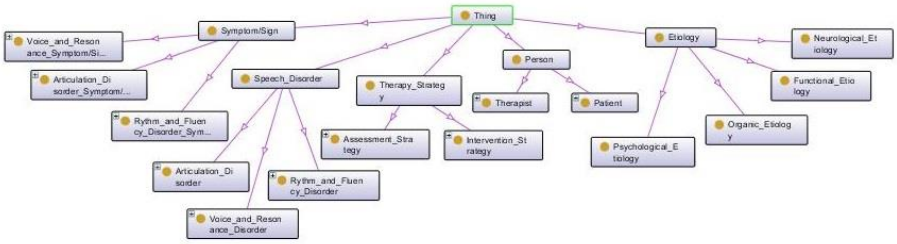

Fig. 4. Hierarchy class diagram.

4.3 Relations Descriptions

Within the ontology there are constraints with respect to the classes of the ontology itself. To begin to describe these constraints it is necessary to consider the relations between classes. In Table 4 some of the identified relations are explained, and each one has an inverse relation, also represented in the ontology.

Table 4. Classes' relation description.

Relation	Domain	Range	Inverse	Cardinality
Affects_to	Speech_Disorder	Patient	Suffers_a	N:1
Applies_a	Therapist	Therapy_Strategy	Is_applied_by	1:N
Evaluates_a	Assessment_Strategy	Speech_Disorder	Is_Evaluated_By	1:1
Gives_therapy_to	Therapist	Patient	Receives_therapy_from	1:N
Has_Cause	Speech_Disorder	Etiology	Is_cause_of	1:N
Intervenes_a	Intervention_Strategy	Speech_Disorder	Is_Intervened_by	1:1
Is_manifestation_of	Symptom/Sign	Speech_Disorder	Is_manifested_by	N:1
Is_shown_by	Symptom/Sign	Patient	Shows_a	N:1

These relations can be visually observed in the following diagram. The relations can be represented as a graph where each class is presented as a node and the edges between nodes are the so called relations between classes (see Fig. 5).

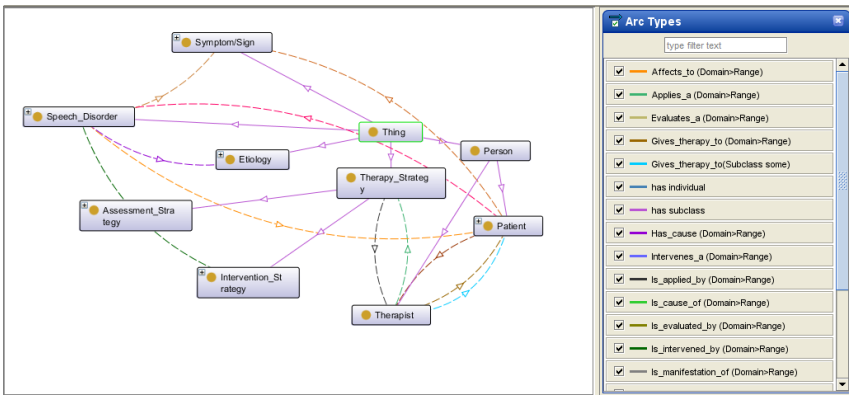

Fig. 5. Relation between classes diagram.

The axioms defining the rules for the ontology are set by the characteristics and the existential restrictions of the non-taxonomic relations. *Object properties* in Protégé are relations between two classes.

The characteristics of the relations could be seen as functions, and in Protégé they are named *property characteristics*; these characteristics that could be associated to a

property (relation) are *Functional*, *Inverse functional*, *Transitive*, *Symmetric*, *Antisymmetric*, *Reflexive* and *Irreflexive*. Some of these characteristics are assigned to each one of the object properties depending on the type of relation between classes that is represented by them; an example can be seen in Figure 6 where property characteristics are assigned to object property *Evaluates_a* and its inverse *Is_Evaluated_by*, being *Functional*, *Inverse Functional* –in the case of the inverse property–, *Asymmetric*, and *Irreflexive* the assigned characteristics, depending on the behavior of each object.

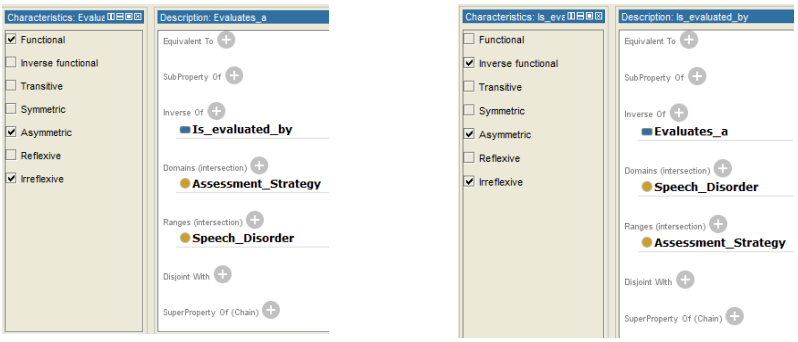

Fig. 6. Property characteristics for relations.

The *Functional* characteristic indicates, for a given relation, that there can be *at most* one range class that is related to the domain class via the property. And if a property is *Inverse functional* then it means that the inverse property is functional. If a property P is *Asymmetric*, and the property relates class *a* to class *b*, then class *b* cannot be related to class *a* via property P. And finally, if a property P is *Irreflexive*, it can be described as a property that relates class *a* to class *b*, where class *a* and class *b* are not the same. In the following image the graph that represents those relations is shown (see Fig. 7).

Other restrictions that help to describe and define classes are the quantifier restrictions, in this case the existential and universal restrictions. Mainly, the quantifier restrictions found in the ontology are existential; this means a class of individuals that have *at least one* (some) relationship along a specified property to an individual that is a member of a specified class.

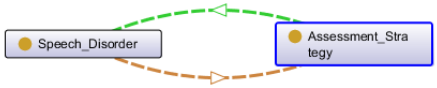

Fig. 7. The *Evaluates_a* and *Is_evaluated_by* relations represented as a graph.

4.4 Consistency Test

In order to probe the consistency of the built ontology Protégé's logical reasoner is used with the *probe class* technique. This means adding an inconsistent class to probe the integrity of the ontology. In this case a new class was added: *InconsistentDisorder*, which is a subclass of *Articulation_disorder* and of *Voice_and_Resonance_Disorder*,

simultaneously. After invoking the reasoner to probe the consistency of the added class an error is shown because its super classes are disjoint from each other. The consistency test is shown in Figures 8 to 11, along with the defined class properties and the resulting error.

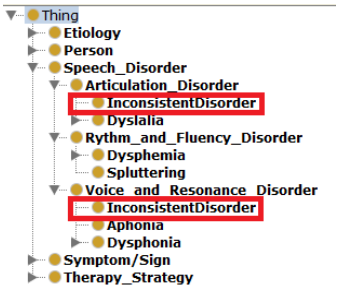

Fig. 8. Probe class added.

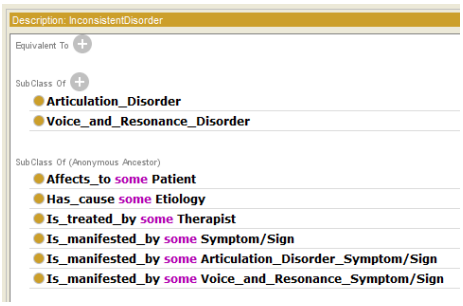

Fig. 9. Probe class characteristics.

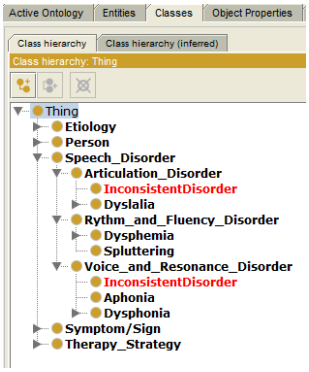

Fig. 10. Inconsistency after running the reasoned.

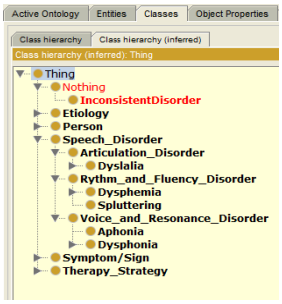

Fig. 11. Inconsistency in the inferred Hierarchy.

4.5 Primitive and Defined Classes

The classes previously created have just necessary conditions to describe them and these types of classes are called Primitive Classes. A necessary condition means that if something is a member of such class then it is necessary to fulfill certain conditions. Using just necessary conditions, it is not possible to use those conditions backwards, this means, it is not possible to say that if something fulfills the conditions then it must be a member of such class.

On the other side, if an individual fulfills a set of sufficient conditions, that is enough to determine that any (random) individual must be a member of such class. A class that has at least one set of *necessary and sufficient* conditions is known as a *Defined Class*. Figure 12 shows the difference between a Primitive and a Defined Class [18], while some examples of Defined Classes (*Patient* and *Therapist* classes) in the ontology are shown in Figure 13 with their sets of conditions [17].

With all these characteristics and restrictions defining and describing the classes the ontology can now be used to answer the competency questions and infer knowledge,

and the information can be made available for a larger number of users like therapists and patients.

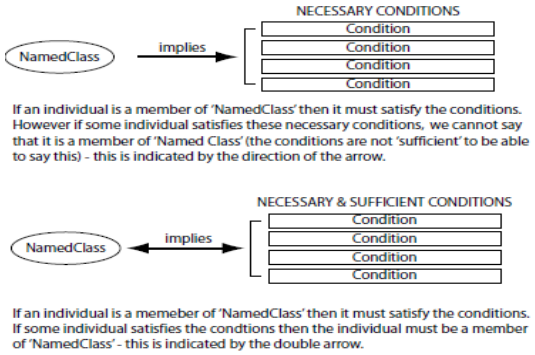

Fig. 12. Necessary and Sufficient conditions.

The population of the ontology was made with data gathered from therapists working in public institutions such as elementary schools; the instances of the class *Person* are the individuals represented with such data. Some evaluation work along a group of therapists to test the efficiency and usefulness of this ontology as a diagnosis tool is in progress.

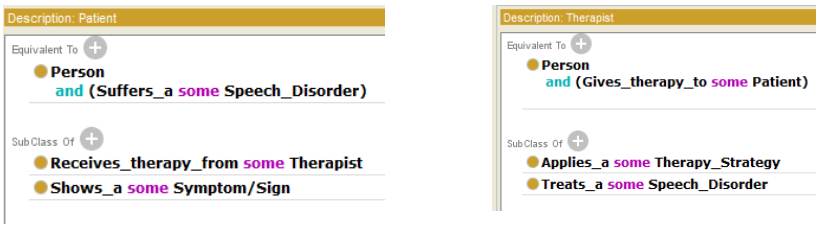

Fig. 13. Defined Classes in ontology.

5 Results and Conclusions

As a result, a first version of the ontology that is consistent has been obtained, the built taxonomy was defined with five main classes, and more than one hundred subclasses, eighteen relations between individual were identified, the existential restrictions and characteristics for the classes were set and the definition of primitive and defined classes were also completed, making this ontology a tool that is used for information description, and, using it to model the information of a structured environment, allows us to answer questions related to the competence area. The ontology could be helpful in situations when a therapist is in need of theoretical information for an accurate diagnose, to formulate a therapy plan, or to obtain a report with the characteristics, symptoms and signs presented by a patient. Moreover, the ontology can be used to provide information to the patient and his/her family about a specific speech disorder.

6 Future Work

As a future work we propose the use of an audio transcription tool, as well as analyzing that data in order to detect some speech disorder and its possible classification using the present ontology as a knowledge-base for this purpose. A simple analysis of transcript text by metrics like Levenshtein distance could detect the insertion, omission, substitution or repetition of speech sounds. Google Cloud Speech-to-text has useful characteristics like real-time transcription, recognition of variation in the pronunciation of sounds and less word correction [19].

References

1. NICHCY: Trastornos del habla o lenguaje. 0285, pp. 1–4 (2010)
2. Global Disability Rights Now!: Disability in Mexico
3. WHO (World Health Organization): World report on disability 2011. Am. J. Phys. Med. Rehabil. Assoc. Acad. Physiatr (2011)
4. Robin: What is Corpus? Natural Language Precessing. Available in: http://language.worldofcomputing.net/linguistics/introduction/what-is-corpus.html (2009)
5. Sharma, S., Ward, E.C., Burns, C., Theodoros, D., Russell, T.: Assessing dysphagia via telerehabilitation: Patient perceptions and satisfaction. Int. J. Speech. Lang. Pathol. 15, pp. 176–183 (2013)
6. Schipor, O.A., Pentiuc, S.G., Schipor, M.D.: Automatic assessment of pronunciation quality of children within assisted speech therapy. Elektron. ir Elektrotechnika. 122, pp. 15–18 (2012)
7. Martín Ruiz, M.L., Valero Duboy, M.Á., Torcal Loriente, C., Pau de la Cruz, I.: Evaluating a web-based clinical decision support system for language disorders screening in a nursery school. J. Med. Internet Res. 16, e139 (2014)
8. Robles-Bykbaev, V., López-Nores, M., Pazos-Arias, J., Quisi-Peralta, D., García-Duque, J.: An Ecosystem of Intelligent ICT Tools for Speech-Language Therapy Based on a Formal Knowledge Model. Stud. Health Technol. Inform. 216, pp. 50–54 (2015)
9. Chuchuca-Mendez, F., Robles-Bykbaev, V., Vanegas-Peralta, P., Lucero-Saldana, J., Lopez-Nores, M., Pazos-Arias, J.: An educative environment based on ontologies and e-learning for training on design of speech-language therapy plans for children with disabilities and communication disorders. In: CACIDI 2016 - Congr. Argentino Ciencias la Inform. y Desarro. Investig. (2016)
10. Ilda, R., Torres, B., López, I.V., Luis, J., Suarez, D.: Aplicación Móvil para la Adquisición de Lenguaje en Niños con Trastorno de Habla. Pistas Educativas 122. Tecnológico Nacional de México, Instituto Tecnológico de Celaya, pp. 40–56 (2016)
11. Kalra, D., Beale, T., Heard, S.: The OpenEHR foundation
12. Wynne, M.: Developing Linguistic a Guide to Good Practice Corpora (2005)
13. Mitchell, R.: Web scraping with Python: collecting data from the modern web. O'Reilly Media, Inc. (2015)
14. Princeton University: About WordNet - WordNet, http://wordnet.princeton.edu/wordnet/
15. Gallardo Ruíz, J.R., Gallego Ortega, J.L., Valcárcel Castilla, J., Pardal Rivas, C., Vilchez García, V.: Manual de logopedia escolar: un enfoque práctico. Aljibe, Málaga (2000)
16. Gómez-Pérez, A., Fernández-López, M., Corcho, O., Gomez-Perez, A.: Ontological Engeenering. Springer (2004)
17. Musen, M.A.: The Protégé project: A look back and a look forward. AI Matters. Assoc. Comput. Mach. Specif. Interes. Gr. Artif. Intell. 1, (2015)
18. Prot, U.H.M., Knublauch, H., Rector, A., Stevens, R., Wroe, C., Jupp, S., Moulton, G.,

Drummond, N., Brandt, S.: A Practical Guide To Building OWL Ontologies Using Protégè 4 and CO-ODE Tools Edition 1.3. Matrix. 0–107 (2011)
19. Google Cloud: Cloud Speech-to-Text - Speech Recognition