Educational Thesauri for Mastering Engineering Courses

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***Abstract-* The paper focuses on the information system the core component of which is an educational thesaurus. The learning management system basing on the appropriate educational thesauri and effective procedures of their filling and ranking are proposed. An analysis carried by the authors revealed the drawbacks of the conventional learning tools and became the initial point for the development of the new knowledge resource. To meet learners' expectations, the principles of the educational thesaurus design are proposed in the paper. Following these principles, effective procedures and algorithms of data filling and ranking were developed that prevent conceptual recursion and repetition, restrict the number of predetermined concepts in the articles, and promote concept redefining. Cited examples and implementation results confirm the thesaurus suitability for learning management. As opposed to the traditional environment, the system allows finding the starting position at which concepts may be introduced. The thesaurus simplifies conceptual understanding both for students and teachers.**

I. INTRODUCTION

Through experience and education people acquire knowledge about the surrounding world that includes information, facts, descriptions, and skills. Every educational system is oriented on increase of the knowledge volume. Schooling, study, observation, and practice supply an individual with *concepts*, elementary objects of knowledge composed of the unique combination of characteristics. All the concepts may be divided into the known and unknown ones. During the educational process a learner crosses a succession of knowledge levels (courses) thus obtaining new conceptual understanding of the universe. In this way, a balance of the known and unknown concepts changes gradually as a student passes from one academic course to another.

The knowledge level of an individual may be evaluated by the personal *thesaurus*. According to [1], a thesaurus represents a compendium of a body of knowledge with the structured controlled relationship of concepts within an application area. In most cases the personal thesaurus is the collection of known concepts that concerns some delimited field of human interest, while the "universal" encyclopedia, multiple dictionaries and glossaries can be referred to as compendiums of all human knowledge, both known and unknown for the individual.

Each thesaurus entry is an article devoted to a separate concept, including its title and definition. All the thesaurus articles are directly and indirectly connected with each other. Generally, the direct links have the alphabetic and thematic nature of the concept titles. The indirect links are implemented throughout the concept definitions which expose a concept by dozens of other concepts. A degree of the conceptual understanding from the thesaurus depends on the learner knowledge of the concepts used in definition. The presence of unknown components impedes progress in learning.

Many thesauri types exist, such as encyclopedic and explanatory dictionaries, professional glossaries, reference books, etc. Part of them belongs to the online tools, the most powerful of which are Wikipedia.org, Thesaurus.com, Ask.com, Thefreedictionary.com, Visualthesaurus.com, etc. The online glossary Electropedia.org covers explanations of the concepts relevant to Electrical Engineering.

Numerous methods have been developed for the thesaurus presentation [2]. Traditional offline encyclopedic and explanatory dictionaries have the article structure. To explore them, the theory of syntax [3] is used. Higher effect brings separate processing of the titles and definitions. Multiple database technologies and list handling methods along with matrix approaches are applied to study the separated entries [4]. As well, many treelike algorithms were designed to optimize and enhance the entries [5]. Generally, a modified family tree, or pedigree chart [6], may successfully represent conceptual relationships, starting from the root (ancestor) and ending by the leaf (descendant) concepts. Unlike a conventional family tree structure, the number of ongoing brunches for a thesaurus tree node is not limited by the couple of parents whereas each node has only one outgoing child branch.

The present work focuses on the development of a new tool, namely educational thesaurus (ET). In contrast to other thesaurus types, it is intended primarily for learning. Every course studies the concepts in a specific context, giving them distinctive meanings that may deviate from the meaning the same words have in other contexts and in everyday language. Taking into account this target, the ET structure and the definition part require a unique arrangement explained in the paper. Following the analysis of the ordinary thesauri shortcomings from the viewpoint of educational purposes, the new principles of the ET arrangement are proposed. Then, the methods of thesaurus filling and ranking are developed and an example of their application is given. The results of the ET implementation are presented in the final part of the paper.

II. ANALYSIS OF THESAURI

Let us call the concepts given outside an academic curriculum as *terms*. The meaning of terms a learner knows at the on-going stage of a course. Further, call the concept the meaning of which is described by the current thesaurus entry, as a *defined concept*, whereas the entries earlier introduced in the course as *predetermined concepts*.

As an example, analyze the definition of the concept "electronics" from the viewpoint of learning suitability and comprehension.

According to Wikipedia, "*Electronics* is the brunch of science, engineering and technology that deals with electrical circuits involving active electrical components such as vacuum tubes, transistors, diodes and integrated circuits, and associated passive interconnection technologies". Let "science", "engineering" and "technology" be the terms. All the other concepts used in the definition, such as "electrical circuits", "active electrical components", "vacuum tubes", "transistors", "diodes", "integrated circuits", and "passive interconnection technologies" undoubtedly belong to electronics. Therefore, a student who decided to enroll electronics cannot understand its meaning until he/she knows the predetermined concepts. Proceed through the link "active electrical component" to understand its meaning. Here, Wikipedia passes you over the predetermined concept "passivity" which is opposite to the active component: "A component that is not passive is called an active component". Following the next link, a learner recognizes an electronic component as "a basic electronic element" and, using the latter link, returns to "*electronics*".

Replace Wikipedia by Visualthesaurus.com to solve the same problem of "*electonics*" understanding. This powerful graphical thesaurus defines "*electronics*" as "a brunch of physics that deals with emission and effects of electrons and with the use of electronic devices". Note that this definition is outdated because "emission" relates to the vacuum tubes practically unused in the modern industry. Let "physics", "emission", and "electrons" be the terms introduced earlier in physics. Therefore, to understand "*electronics*", the student must know the meaning of "electronic device". Following the link, find out that "Electronic device is a device that accomplishes its purpose "electronically". What does "electronically" mean? The thesaurus answers: "Electronically - by electronic means" and finally returns the learner to "*electronics*".

At last, address Electropedia.org: "*Electronics* is a branch of science and technology dealing with the motion of charge carriers in vacuum, gas or semiconductor, the resulting electric conduction phenomena, and their applications". In turn, find out that the "charge carrier" is "a particle, such as an electron or a hole, having non-zero electric charge". And finally, "Hole is a vacancy behaving like a carrier of one positive elementary charge". Thus, the circle closed up!

Conclude the analysis.

1. In most thesauri, *concepts are defined through their parts*. For instance: "House is a building consisting of windows, doors, roof, etc". Thus, a reader cannot recognize the concept until he/she understands its parts.
2. The popular thesauri are unprotected from the *recursion* at which the concept in question is indirectly defined through itself. For instance: "A book is a set of pages". "A page is a part of the book".
3. Often, *neglecting* is used in a definition, i.e. it is a concept defined through the neglecting concept. For instance: "Truth is not False". Thus, to understand the concept a user must recognize the opposite concept.
4. Many thesauri are *indifferent to the synonyms*. Particularly, multiple Wikipedia articles explain the sense of the same concepts independent of each other.
5. Generally, the thesauri do *not support redefining* of the concepts. Their definitions are absolute and cannot be adapted to the reader's knowledge level.
6. As the number of predetermined concepts is not restricted, finding the sense of the defined concept can take much time and effort.

Hence, the traditional thesauri do not meet learners' expectations and prevent success in learning.

III. Principles of Educational Thesaurus Arrangement

Assume an ET comprises m entries. Describe each of m concepts CON_i by an i-th entry with the following components:

$$CON_i = \{i, Title_i, D_i(C_{i1}...C_{ip})\} \quad (1)$$

where $i = 1...m$, $C_i \neq CON_i$, $p < m$. Here, i is an index, *Title* is the title, and D is the definition of the defined concept; C are the titles of the predetermined concepts used in the definition of CON_i. Formulate now the main principles of ET arrangement that help to overcome the drawbacks of the traditional thesauri from the educational viewpoint.

Principle A. In the definitions $D_i(C_{i1}...C_{ip})$, the application focus and/or the main operation principle of the defined ET concepts must be outlined. It is prohibited to explain thesaurus concepts through their parts and opposite concepts. This means the predetermined concepts are to be introduced into the thesaurus before the defined concept. Hence, a properly designed ET should be presented by the left-triangular matrix.

Principle B. The first concept CON_1 is to be the heading of the current course defined through the terms foregoing this course ($p = 0$). This will result in the learners' understanding of the course goals and requirements before enrolment. If the thesaurus is presented by the list, relational database or matrix, the starting concept will be the first ET line or row:

$$CON_1 = \{1, Course\ title, D_1(0)\}. \quad (2)$$

If the thesaurus is drawn by the tree, the course heading will occupy the tree root that is the node without the ongoing branches. For instance, for the first entry of the course "Electronics" the following definition of "electronics" meets the proposed principles: "*Electronics* is a field of science, engineering and technology dealing with semiconductors and, rarely, with vacuum tubes". All the components of this definition are the terms foregoing the course. No predetermined concepts are used in the definition. Neither parts, nor the opposite concepts are used. Other examples will be given below.

Principle C. It is reasonable to restrict the number of predetermined concepts by two or three ($p < 4$). The definitions based on the greater number of the predefined concepts require much time and effort for understanding.

Principle D. As the synonyms are the usual ET entries, all the synonyms must be referenced to the uniform definition within the thesaurus.

Principle E. ET must be accomplished with the tools that prevent recursion during the thesaurus filling. Such kind of software is the mandatory part of the ET. At the same time, do not confuse synonyms with repetition. Hence, the ET must be accomplished with the tools that prevent repetition during the thesaurus filling.

Principle F. Redefining of the concepts is the normal situation in education. While the first definition is simple and short, the following ones may be more complex and detailed as they are based on the new concepts introduced throughout the course duration.

IV. Filling the Thesaurus

An object-oriented approach [7], [8], [9] is an effective method of the ET design. The class-built object-oriented ET model is shown in Fig. 1. Here, the *Thesaurus* plays the role of an abstract generic class. The members of the class include the public property *Title* which identifies the objects, and the abstract procedures *Get*() which serves to obtain the required object data, *Find*() to search an object, *Put*() to place an object into the thesaurus, and *Del*() to delete an object from the thesaurus.

Derived class *Concepts*
Properties: i, $C_1 ... C_p$
Procedures: $Get(i, Title, C_1 ... C_p)$,
$Find(i, Title, C_1 ... C_p)$,
$Put(i, Title, C_1 ... C_p)$, $Del(i, Title)$

Generic class *Thesaurus*
Property: *Title*
Abstract procedures: *Get*(), *Find*(), *Put*(), *Del*()

Fig. 1. Class-built model of ET.

Basing on the class *Thesaurus*, the derived class *Concepts* is established. In addition to the inherited property *Title* it involves a property i, which designates the starting time of the concept definition. Traditionally, the time is measured by the academic weeks though other, more flexible units may be used instead. Other class components are the private properties $C_1 ... C_p$ that identify the predetermined concepts. The behaviour of a concept is described by the renewed procedures. The procedure $Get(i, Title, C_1 ... C_p)$ acquires the title and the predetermined concepts of a new object. The procedure $Find(i, Title, C_1 ... C_p)$ searches a concept in the thesaurus whereas $Put(i, Title, C_1 ... C_p)$ places it into the thesaurus along with i calculation, and $Del(i, Title)$ erases a useless concept.

The main problems with respect to adding the concepts to the thesaurus are protection from repetition and providing the redefining. The system must distinguish the particular concept as a new or existing one. The concept identified as a new one is subjected to be inserted into the thesaurus whereas the existing concept is denied. An important task of this procedure is to measure a degree of equivalence between the presented and available concepts. In fact, the system should search and measure a portion of information in the introduced concept. Different searching methods have been developed for this purpose though all of them do not fit the problem. The specific ET peculiarity is an uncertainty of the search key. As it depends on the previously inserted concepts, addition of each new concept may cause the key correction. For this reason the parsing is used in the search procedure proposed below.

The successful parsing may be executed using the rules of the N. Chomsky generative linguistics [3]. First, to check the concept integrity, all the predetermined concepts that define the presented one are included in the search key. If this step fails, the content is divided into the groups having the particular keys C_{ip}, which may be divided again until the nearest concept will be found or the search fails. Thus, the search in the thesaurus is described by the following chain of operations:

$$i = Find(Title_i, C_{i1} ... C_{ip}) \quad (3)$$

$$\text{or } i = Find(Title_i) \quad (4)$$

$$\text{or } i = Find(Title_i, C_{i1}) \ ... \ Find(Title_i, C_{i1} ... C_{ip\text{-}1}) \quad (5)$$

Other algorithms of the group definition are also possible. In this way, the parsing tree is generated to evaluate the equivalence rating.

The thesaurus is filled by the concepts in the following manner.

The procedure *Get* acquires new concepts. The procedure *Find* searches for the concept title in the thesaurus and returns the properties i and $C_1 ... C_p$ of the concept detected. Next, this result is used by the procedure *Put*, which compares the received variables $C_1 ... C_p$ with the values given by the procedure *Get*. If the concept is not defined yet, the procedure *Put* will add it into the thesaurus at the lowest timing position i.

On the other hand, the concept may be detected in the thesaurus as an incomplete entry without some components from the list $C_1 ... C_p$. In this case, the procedure *Put* enters the concept into the thesaurus again (redefines it) and indicates the value i obtained from the detected concept. In addition, the new components of $C_1 ... C_p$ are placed into the renewed concept. To calculate the time i, the procedure *Find* searches the values i of all predetermined concepts given by the list $C_1 ... C_p$. The greatest of the values $i = i_{\max}$ represents the seeking value $i > i_{\max}$ of the renewed concept. In this way, the proposed method protects the thesaurus from the concept repetition and supports conceptual redefining.

Finally, the procedure *Del* erases the obsolete entries.

V. RANKING THE THESAURUS

As the predetermined concepts are introduced into the ET before the defined concept, a properly designed thesaurus should be ordered. Ranking of the unordered thesaurus is the next problem faced by the thesauri developers [10], [11].

Many sorting algorithms were described in literature, starting from [4], [5]. Nevertheless, unlike the simple data list, the key of the thesaurus sorting is an unknown earliest position i at which a defined concept may be introduced into the learner's knowledge area. This parameter should be derived based on the known concepts $C_1...C_p$, predetermined the ranged concepts. Unless a designer introduces a concept in time, the concept doubling occurs that complicates conceptual comprehension. First, this draws out the learning period. Second, the professional knowledge structure entangles unreasonably. Additionally, learning loses its clarity and attractiveness.

Let i be a permissible instant to introduce the concept CON_i. Let a length of an educational trajectory be measured by a number of concepts m. Let $m = m_1 + m_2$, where m_1 be the minimal number of concepts and m_2 be a number of redefined concepts additionally introduced into the thesaurus. The greater is m, the longer is an educational trajectory.

Assume CON_i is a defined concept and C_j is a predetermined concept from the definition of CON_i, $j = 0...p$, $C_j \in \{CON_1, CON_m\}$. A defined concept CON_i depends on some predetermined concepts C_j and does not depend on the remaining concepts from m. The greater is i, the later a concept CON_i should be introduced into the learner's knowledge area.

State the following research problems:

Problem A. Find $\min(i)$ that is the minimum possible index of the defined concept CON_i.

Problem B. Find $\min(m)$ that is the minimum possible number of the intermediate concepts of an educational trajectory within the course.

In the simplest case, when $j = 0$ (no predetermined concepts), $i = 0$, which means that all such concepts CON_i may be introduced starting from the course beginning. Further problem is to rank the remaining concepts CON_i predetermined by C_j of the same course.

TABLE I.
THESAURUS MATRIX

i	*Title*	C_1	C_2	...	C_j	C_{j+1}	...	C_m
1	*Title* $_1$	$w_{1,1}$	$w_{1,2}$	...	$w_{1,j}$	$w_{1,j+1}$	...	$w_{1,m}$
2	*Title* $_2$	$w_{2,1}$	$w_{2,2}$	...	$w_{2,j}$	$w_{2,j+1}$	...	$w_{2,m}$
:	:	:	:	:	:	:	:	:
i	*Title* $_i$	$w_{i,1}$	$w_{i,2}$	...	$w_{i,j}$	$w_{i,j+1}$	...	$w_{i,m}$
i+1	*Title* $_{i+1}$	$w_{i+1,1}$	$w_{i+1,2}$	...	$w_{i+1,j}$	$w_{i+1,j+1}$	...	$w_{i+1,m}$
:	:	:	:	:	:	:	:	:
$m-1$	*Title* $_{m-1}$	$w_{m-1,1}$	$w_{m-1,2}$	...	$w_{m-1,j}$	$w_{m-1,j+1}$	...	$w_{k-1,m}$
m	*Title* $_m$	$w_{m,1}$	$w_{m,2}$	...	$w_{m,j}$	$w_{m,j+1}$		$w_{m,m}$

In the common case, the thesaurus may be represented by the rectangle matrix of m rows and m+2 columns shown in Table 1, where $w_{j,j} \in \{1, 0\}$ are the binary connection weights. Consequently, present an i-th predetermined concept group as follows:

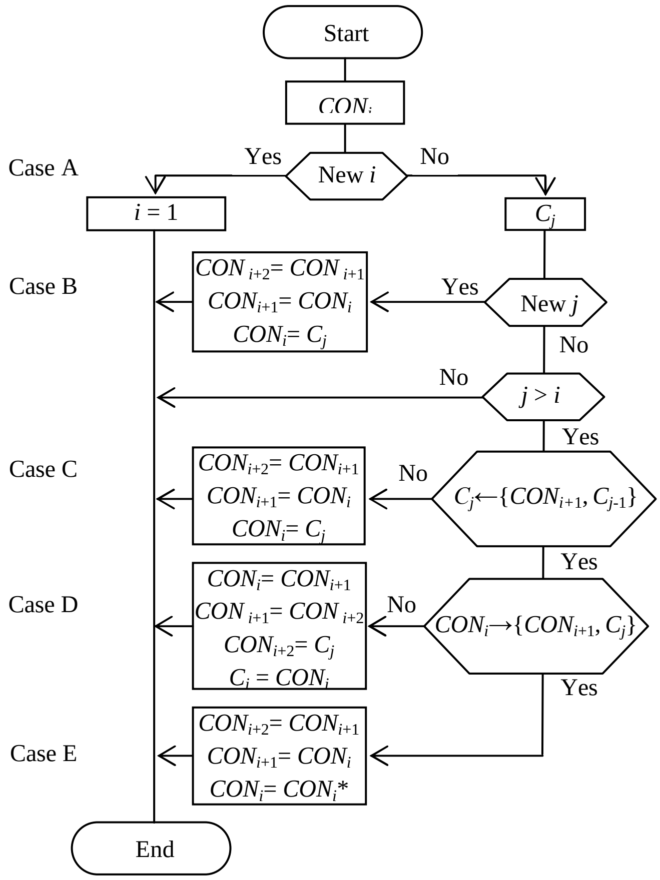

Fig. 2. Algorithm of the thesaurus ranking.

$$C_{i\Sigma} = m(C_j \cdot w_{i,j}) = C_1 \cdot w_{i,1}, C_2 \cdot w_{i,2}, \dots, C_m \cdot w_{i,m} \quad (6)$$

where the universal qualifier $m(C_j \cdot x_{i,j})$ comprises all the predetermined concepts that define CON_i and j is an index of the matrix column. As the predetermined concepts are introduced into the curriculum before the defined concept, a properly designed thesaurus should be ordered and described by the left-triangular matrix as follows:

$$\begin{aligned} &w_{i,j} = 0 \text{ when } j \geq i, \\ &w_{i,j} \in \{0, 1\} \text{ when } j < i. \end{aligned} \quad (7)$$

To rank the thesaurus, which does not satisfy these conditions, the following procedure shown in Fig. 2 was developed.

Case A. If an index i of CON_i is not determined yet, set $i = 1$ meaning this concept can be introduced in the beginning of the course.

Case B. If the j-th predetermined concept C_j of CON_i is not determined yet, increase i of both the defined concept CON_i and all the concepts following CON_i and place C_j in the emptied line i, instead of CON_i.

Case C. If the j-th predetermined concept C_j of CON_i is placed after CON_i and there are no concepts between CON_i and C_j which define C_j, then lift C_j on the place of CON_i and drop CON_i and all the following concepts to the emptied position.

Case D. If the j-th predetermined concept C_j of CON_i is placed after CON_i and there are no concepts between CON_i

and C_j which depend on CON_i, then move CON_i straight behind C_j.

Case E. If the j-th predetermined concept C_j of CON_i is placed after CON_i and there is a concept between CON_i and C_j which either depends on CON_i or defines C_j, the intermediate concept CON_i* is to be introduced for CON_i redefining. This concept serves as a new simplified definition of CON_i which uses only the superincumbent concepts. As the concept CON_i* was not determined yet, increase i of both the defined concept CON_i and all the concepts following CON_i, and place CON_i* in the emptied position i instead of CON_i.

Taking into account that i is the minimum permissible index of CON_i, the indexes i of other concepts CON_i may further be exchanged using the algorithm given above. Thus, the designer obtains an instrument to find the best position for a concept introduction into the course.

VI. Application Example

Assume an ET fragment of the course *Electronics* includes some concepts, like these:

1. breakdown − reverse voltage of a pn junction where the Zener effect occurs
2. diode − two-terminal semiconductor device serving as a conductor being forward biased and as an insulator being reverse biased
3. *pn* junction − area between *p*-type and *n*-type layers
4. Schottky diode − high-frequency diode with no depletion layer
5. intrinsic semiconductor − single-element semiconductor without *pn* junction
6. Zener diode − diode designed to operate in the Zener effect area
7. Zener effect − effect of high current occurring in a diode under certain reverse voltage
8. *p*-type − trivalent impurity of an intrinsic semiconductor
9. *n*-type − pentavalent impurity of an intrinsic semiconductor

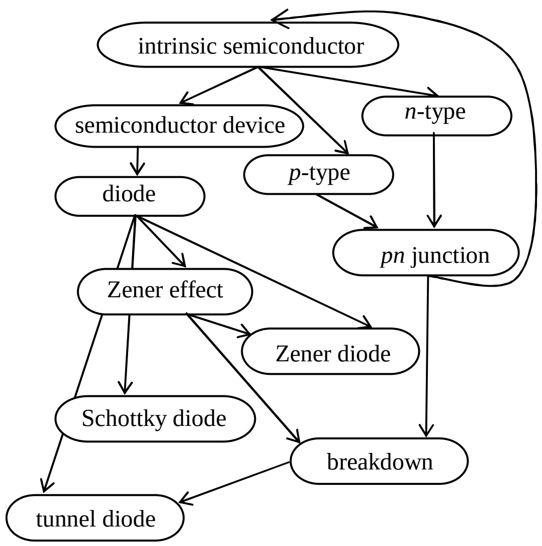

Fig. 3. Fragment of a concept tree.

10. tunnel diode − heavily doped diode with a zero breakdown
11. semiconductor device − electronic device built on intrinsic semiconductors with impurities

Here, the underlined words are the new concepts whereas other words were introduced before this fragment. The defined concepts occupy the left side of each definition whereas the predetermined concepts are to the right. The concept tree of titles for this fragment is shown in Fig. 3.

Table 2 represents the structure of the same fragment.

TABLE II.
Fragment of Unordered Concept Table with Recursion

i	*Title*	C_1	C_2
1	breakdown	Zener effect	*pn* junction
2	diode	semiconductor device	
3	*pn* junction	*p*-type	*n*-type
4	Schottky diode	diode	
5	intrinsic semiconductor	*pn* junction	
6	Zener diode	diode	Zener effect
7	Zener effect	diode	
8	*p*-type	intrinsic semiconductor	
9	*n*-type	intrinsic semiconductor	
10	tunnel diode	diode	breakdown
11	semiconductor device	intrinsic semiconductor	

An analysis shows the presence of a recursion and an unordered fashion of the fragment. To exclude these shortcomings, the ranking procedure was executed. Ranking resulted in exclusion of the curved link between "*pn* junction" and "intrinsic semiconductor" in Fig. 3. Table 3 displays the finally ranked ET.

TABLE III.
Fragment of Correct Concept Table

i	*Title*	C_1	C_2
1	*pn* junction*		
2	intrinsic semiconductor	*pn* junction*	
3	*p*-type	intrinsic semiconductor	
4	*n*-type	intrinsic semiconductor	
5	*pn* junction	*p*-type	*n*-type
6	semiconductor device	intrinsic semiconductor	
7	diode	semiconductor device	
8	Schottky diode	diode	
9	Zener effect	diode	
10	Zener diode	diode	Zener effect
11	breakdown	Zener effect	*pn* junction
12	tunnel diode	diode	breakdown

Here, the new concept "*pn* junction*" was introduced to give the simplified "*pn* junction" description, like this:

pn junction* − area between the semiconductors with mostly positive and negative carriers

Later, “*pn* junction” is redefined in line 5 of Table 3.

The ranked thesaurus accompanies many electronic documents of the disciplines related to electronics delivered in Tallinn University of Technology. Using interactive hyperlinks, the ET clarifies and explains the sense of concepts through other learning materials, such as lectures and practical guidelines. This hierarchically structured interactive dictionary interprets more than 1000 concepts in electronics. Each of its articles has a semantic (meaningful) relationship with the preliminary given definitions.

The thesaurus is designed using both the database structure and the Concept Map toolbox. In the database table, an alphabetically ordered index of the thesaurus is settled in the initial records. Another choice is a thematic index used to guide the learner throughout the course, from the root concept to the leaves of the knowledge tree.

The concept map [12], [13], [14] serves as the ET graphical organizing tool. It shows the concepts, usually enclosed in circles or boxes of some type, and relationships between the concepts indicated by the connecting lines coupling the concepts. Words on the line referred to as linking words or linking phrases specify the relationship between the linked concepts. The concepts are represented in a hierarchical fashion with the most inclusive, most general concepts at the top or left side of the map and the more specific, less general concepts arranged hierarchically below or to the right. The hierarchical structure for a particular domain of knowledge also depends on the context in which that knowledge is being applied or considered.

VII. CONCLUSION

An analysis carried by the authors revealed the drawbacks of the conventional thesauri from the educational viewpoint and became the starting point for the development of the new tool, namely educational thesaurus. To meet learners’ expectations, the principles of the ET design were proposed in the paper. Following these principles, effective filling and ranking procedures and algorithms were developed that prevent conceptual recursion and repetition, restrict the number of predetermined concepts in the new concept definitions, and promote concept redefining. Cited examples and implementation results confirm the thesaurus suitability for learning management. As opposed to the traditional environment, the system allows finding the starting position at which concepts may be introduced into the ET. Using the thesaurus, both the student and the teacher can follow up the meaning of each concept. Application of the thesaurus is important for the conceptual thinking and understanding of the learning process because a student may learn the discipline in a logical manner, thus creating his/her own professional field of knowledge.

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