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TEACHING, LEARNING, AND ASSESSMENT INTEGRATION IN ELECTRONICS ON THE CONCEPT MAP BASIS

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Abstract. The paper describes the concept mapping technology employment in Electronics education. It is shown that the concept maps represent a suitable tool to support instructors in promoting students' comprehension of the studying material and in improving their conceptual understanding. An original educational thesaurus is introduced that displays the learners what they have acquired from the lessons. It supports them in making connections between new and prior concepts and reinforces knowledge integration by such a promotion. The developed concept maps are regarded as a valuable instrument of many assessment procedures. They represent learners' knowledge providing informative and reflective feedbacks tailored to learners' personal styles and habits.

1 Introduction

Today, many organisations seek better ways to enhance their educational methodologies that, according to the UNESCO publications, should provide novel arrangements for creation, defining, and application teaching, learning and assessment resources and processes with their common integration. The major aim is to design high-quality educational process, which motivates students to learn both the skills directly related to their professions and the additional knowledge domains valuable in the specific working environments.

Knowing how and what students learn is important for judging the appropriateness of learning objectives and deciding instruction improvement. Like in other disciplines, students begin their training in Electronics from the basic concepts with an introductory Electronics and Semiconductor Engineering course that introduces such elementary parts like semiconductors, electronic devices, amplifiers, filters, and digital components. Next, the students continue learning with the Power Electronics course where they study power converters, including their features, connections, major calculations, and development issues. Educators supply the graduates with knowledge about the general concepts in the field and enhance their understanding of ties among other topics for their future studies. At that, both the learners and the teachers face many problems in these.

Instructors regularly expect learners to link for themselves the concepts they learn in Electronics and the objects they study across other disciplines in their curriculum. Doing so, educators bear in mind the new educational technologies that enable trainee to acquire great amounts of studying materials. Often, they supply the students with additional printed and the virtual data. The printed resources involve textbooks, tutorial aids and lecture notes, exercises, labs explanations, quizzes, examination problems, etc. The virtual group covers the e-books, web manuals, software, and databases along with learning portals, webinars, and social networks. The regular learners and educators' exchange upon the partner agreements and international programmes increase the students' activity as well. In addition to the traditional university resources, the learning guides from the partners and enterprises together with the open Web resources are now accessible for learning. Most of them were explained and described deeply in Raud (2012).

The educators are often disappointed when the trainees have failed to connect expected topics: they disregard the situation that wide knowledge proliferation often results in such a serious problem as an information stages (Chen, Kinshuk & Chen, 2006). Doing work without guidance, the students find fragmentary and scrappy information being unable to make complete and systematic knowledge in the field. For students, it is difficult to express a comprehensive map of Electrical Engineering, Electronics, Power Electronics, Physics, and similar domains due the diversity of the concepts in the appropriate curricula. It is not easy to percept the practice and theory behind the studied topics and their interconnections. As the learners find these courses difficult for understanding, their motivation in studying and success of learning are brought down. In (Tokdemir & Cagiltau, 2010), the similar reasons were explained regarding other engineering disciplines.

Many studies focus on the new approaches that enhance the acquisition of large information volumes. In particular, an effective "curriculum container system" has been proposed in (Wu et al., 2005), which five-level composition includes the curriculum, unit, task, episode, and element levels. The educator's activity is restricted in this case by the curricula "aggregates" hence any time when a teacher decides to modify the educational trajectory the curriculum has to be changed. Another popular instrument designed by these authors is a "conceptual graph" for knowledge representation, which more influences on the syllabi volume rather than on the curriculum structure.

The study of (Kavitha, Vijaya & Saraswathi, 2012) applies such knowledge acquisition objects like headings, titles, overviews, previews, typographical cues, summaries, number signs, recall sentences, summary indicators, and indicators of importance that produce larger information storage. Research of (Roy, 2008) has shown that proper arrangement of learning volume and context successfully increases the amount of knowledge that students can acquire as well as their overall comprehension. Particularly, graphical representation of studying volume can reduce the information overload and students' disorientation.

As for now, the concept mapping represents one of the most powerful graphical tools for the knowledge acquisition (Shieh & Yang, 2014; Rudraraju et al., 2014). As follows from (Guastello, Beasley & Sinatra, 2000; Jain et al., 2014; Thanasis et al., 2014), the concept maps scaffold students in understanding the novel topics by mapping the links among new and previously studied domains. In the same way as with other disciplines, Electronics can be discussed as a knowledge domain, which collects some finite volume of concepts and links among these concepts. A representation of such a collection suitable for knowledge reuse and sharing is known as ontology (Gruber, 1993). Commonly instructors apply ontology made by domain experts in the corresponding field of science to prepare their course syllabus in a way that mitigates knowledge overload and information disorientation. Besides, teachers also use ontology to design their tutorial aids and to prepare some learning tools to guide their students (Chandrasekaran, Josephson & Benjamins, 1999). To display ontologies and to transfer them from instructors to trainees, three types of systems are used, namely, mathematical models, descriptive models, and graphical ones (Satzinger, Jackson & Burd, 2000). The concept maps (Novak & Gowin, 1984) as a graphical representation of knowledge comprised of concepts with their relationships successfully demonstrate how to use prior knowledge as a framework for learning the new knowledge. From the constructivist viewpoint, a learner acquires the new knowledge by integrating the new concepts with the existing ones (Ausebel, 1963). This stresses the importance of prior knowledge in learning the novel concepts. In (Raud, Vodovozov & Lehtla, 2010; Raud & Vodovozov, 2011) concept mapping was represented as a first stage in ontology development and used flexibly to display a knowledge topology for meaningful learning together with the educational thesauri.

Basing on the concept mapping methodology, this paper reports about the enhancement and refining of a teaching strategy and technique of Electronics education. The first part of work focuses on the concept map employment in Electronics domain where the authors have developed the set of concept maps and associated graphical network resources. Next, the paper explains how to define the required concepts using multiple knowledge resources, design the requested concept maps, and arrange the learning objects referred to these concepts. In the further sections, it is shown how the concept maps assist learners in understanding the Electronics knowledge domain and the concept cross-linking. The proposed concept maps are employed as an instrument for improving understanding of learned areas both before and after the lessons. Finally, the paper demonstrates how a particular concept status can affect different learning goals thus giving the students some adaptive guidance for the course appreciation.

2 Educational Thesaurus

An effective descriptive model in the form of educational thesauri (ET) has been developed by the authors of this paper as the first step of the Electronics ontology design (Raud, 2012). In contrast to other well-known thesauri, ET was intended primarily for educational purposes. It has been taken into account that every discipline studies the concepts in a specific context and gives them distinctive meanings that deviate from the meaning of the same words in other contexts and in everyday language. A properly organised course ET is described by a direct acyclic graph whereas a speciality thesaurus is represented by the forest of such graphs. Basing on this target, the ET topology estimation and the definition were given in (Raud & Vodovozov, 2011).

To build ET, the key concepts in Electronics were first chosen as candidates to be included to ET (Raud & Vodovozov, 2012). Such concepts proposed by different authors are not always consistent as they often describe the same concepts using similar terms but not exactly the same ones. Therefore, these terms were primarily classified by instructors into appropriate groups to reduce their total number. Next, our purpose was to summarize the large datasets by removing any redundancy in the data for finding the key concepts. At last, an evaluation of "relation strength" was decided.

The ET created to store these grouped terms has become a suitable tool from this viewpoint (Raud, Vodovozov & Lehtla, 2012). Every ET entry represents an article explaining a separate concept, including its term and definition. A concept which meaning is described by a particular entry was called as a defined concept whereas earlier introduced entries used to explain a defined concept were called as parents. Ten lines below represent a very short fragment of an educational thesaurus for the Power Electronics course (Raud & Vodovozov, 2011) where the following concepts are defined:

1. **power electronic converter (PEC) –** *electronic converter* that converts energy in a power electronic system;
2. **dc/dc converter − PEC** converting *dc* to *dc* of another level;
3. **load** − object connected to the **PEC** output;
4. **supply** − *power* line feeding the PEC;
5. **boosting** − generation of the **load** *voltage* which level is higher than the **supply** *voltage* has;
6. **booster − PEC** with **boosting** possibilities;
7. **boost converter – booster**;
8. **switching dc converter − dc/dc converter** built on a *switching* principle of operation;
9. **buck converter − switching dc converter** the output *voltage* of which is less than the input *voltage*;
10. **buck-boost converter – buck converter** combined with a **boost converter**.

Here, the concept terms are given with the bold typeface and an italic font is used for the terms incoming from prior disciplines, such as Electronics and Electrical Engineering. The defined concept terms occupy the left side of each line whereas the definitions are to the right. In Table 1, a fragment of the ordered concept table is presented.

i	Term	Parent 1	Parent 2
1	PEC		
2	load	PEC	
3	supply	PEC	
4	boosting	load	supply
5	booster	PEC	
6	boost converter	booster	
7	dc/dc converter	PEC	
8	switching dc converter	dc/dc converter	
9	buck converter	switching dc converter	
10	buck-boost converter	buck converter	boost converter

Table 1: Fragment of the concept table in Power Electronics

These ranked thesauri now accompany many electronic documents of the courses related to learning Electronics in Tallinn University of Technology. With the help of interactive hyperlinks, an educational thesaurus clarifies and explains the concepts through other learning materials including lectures and practical aids. This interactive hierarchically structured dictionary explains currently about 1000 concepts in the Power Electronics. Every ET entry has a semantic (meaningful) connection with the earlier given definitions. An alphabetically ordered thesaurus index is arranged as the database table. In addition, a thematic index exists which guides the learner throughout the discipline, from the root concept to the leaves of the knowledge tree.

3 Concept Maps as a Teacher Tool

Following (Villalon & Calvo, 2008), the above approach applied to teaching Electronics represents accurate information about the knowledge domains studied. As any map is a graphical representation of a more or less ET fragment, during the map development we selected the set of concepts and the linking words to arrange the basic propositions in the field. These concepts were accomplished in a proper topology at which concepts that are more general appear higher in the map, and concepts that are more specific occupy lower levels. Concepts within the same level of generalization were located on the common topological levels. Therefore, the outcome of our concept mapping has comprised of concepts, relationships, and a topology.

In (Chen, Kinshuk & Chen, 2006), the procedure of knowledge transfer has been shared between four main steps:

- information retrieval,
- concept extraction,
- search for the key concepts,
- evaluation of "relation strength".

Accordantly this organisation, before constructing a concept map for a domain, every teacher in our team has distinguished between content covered through lecturing and content provided through labs, exercises, and other studies. Additionally, such informational resources as textbooks, scientific and popular books, and websites supply the students with required data also. To arrange successful concept extraction, the instructors collected their terms in an educational thesaurus where they summarised large datasets and removed data redundancy. During this process, the evaluation of concept "relation strength" has been decided. In the simplest case, a linear map topology without loops and with minimal concept linking could be proposed. However, as far as many concepts have complex interconnection and, on the contrary, some concepts have no links with other concepts, the teachers minimized such decoupling using the peer-to-peer communication.

We have found that a focus question of the particular lesson should be interpreted by no more than 25 concepts. This demand affects concept mapping with minimal redundancy and minimal loss of information. Therefore, simplicity is the first important instructor's requirement. If a concept set is too large, several concept maps can be used. In the same way, summaries were created for a chapter and for a part of the studied domain.

Concept maps of different instructors are subjective, because every concept map represents the author's individual knowledge and skills. In an educational context, a teacher wants to infer the student's understanding and perspective on a topic. The educator also wants that terminology used by the student would enable assessment of the outcomes, so the concept maps should be represented by different resources in the same way, i.e. using the same words. This requirement affects concept mapping in two ways:

- the concepts and relations are to be extracted from a common basic ET;
- the concept hierarchy has reflect the importance of the concepts in the particular domain.

Based on the above regulations, the major problem in the concept map design was to discriminate the most meaningful concepts from the less important ones. Thus, the first step taken by the instructors was to consider which concepts are most essential, those that the student should not obviate. The second step of a concept map creation was to join the concepts in a meaningful information structure. In this way, a specific network was designed consisting of concept nodes (points, vertices) and links (arcs, edges) which provides such relations among concepts as "is a", "related to", or "part of". Besides these two steps, another quality details have appeal the map designer's interest, such as segregating of the major concepts from the rest using different highlighting (colours, fonts, shapes, etc.), representative figures, icons, and connecting to external websites, applications, or the concept maps from other institutions. The maps developed also include cross-links between concepts of different domains that show how one knowledge domain is related to another domain.

Figure 1 represents a fragment of the thesaurus designed for Power Electronics in the CMAP Tools environment. All the maps developed include the nodes with the key concepts enclosed in rounded rectangles. Each concept has the individual definition label. In the topology, the concepts are represented in a hierarchical fashion with the most general concepts at the left side and the less general concepts arranged hierarchically to the right. Concepts of the equal generalization level are located on the same topological level. The hierarchy of a particular sub-domain is also defined on the context in which its information is being applied or considered. The cross-links are shown in the map as the named shortcuts. As a result, the outcome of the concept maps comprises concepts, relationships and a topology.

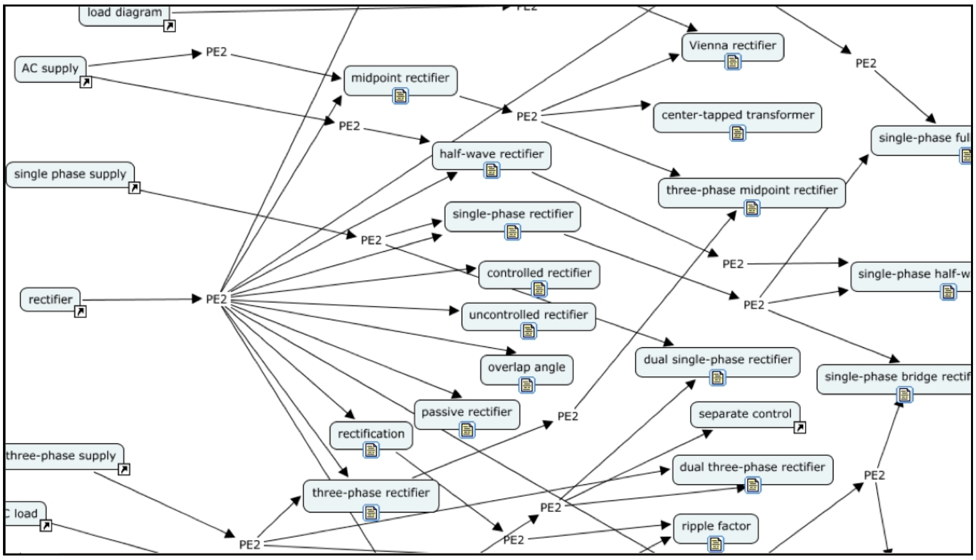

Figure 1. Fragment of concept map in Power Electronics.

The concept maps developed have become a suitable instrument supporting the teachers in promoting students' comprehension of the learning material and improving their understanding of new material.

4 Concept Maps as a Student Tool

The aim of concept mapping for learners is to interpret learners' personal understanding and their possibilities to draw individual examples against the existing theoretical and practical tasks. As the concept maps display graphically some of ET fragments being a flexible tool to focus attention on important aspects of knowing, they help to explore what students actually learn and how they do it.

Our mapping experience demonstrates what learners see as important concepts and how they relate these concepts. The results of mapping have implications for clarifying the learning objectives, refining instructional strategies, identifying appropriate assessment tools, and understanding how the learning objectives are being realized by students.

In the designed system, the concept maps are used for learning using one of the two ways:

- students are asked to develop their own concept maps following a topic in the focus
- students are asked to analyse some preliminarily designed concept maps built by instructors or other learners

Both approaches look to be effective tools in improvement of the learning outcomes. These maps engage in a process of reflection, collecting and selecting appropriate knowledge. We agree with (Bozhko & Heinrich, 2011) that the concept maps allow students

- to develop a flexible structure for self-directed learning;
- to manage large amounts of information in the knowledge base which they build in the learning process;
- to track personal progress in various areas and aspects;
- to share their maps with others for feedback or evaluation;
- to facilitate setting up the personal learning goals.

When concept maps are designed in the classroom, we follow the recommendations of (Chang & Tsai, 2005) and restrict usually the mapping time by 5 to 20 minutes. On the contrary, if mapping specifies the homework, learners will have a lot of information from numerous sources, such as books, Internet, and other digital media libraries. The contents of these sources can be useful to appreciate the course or to simplify knowledge understanding. Otherwise, it is not a trivial job for students to organize and identify the main thematic topics. Therefore, the students force multiple learning objects and make notes in their concept maps to personalize learning and to re-enforce it for increasing skills and promising the knowledge sharing.

The hierarchical nature of the concept map allows organizing concepts from the high abstract level to more specific layers. This property can be used by students for managing and structuring data. Following the qualitative analysis techniques, our students create their own relations for the concepts that later form their personal concept maps. The learners can also be provided with a map structure predefined by teachers. Moving through the study program, they can learn to understand these concepts and recognize the valuable examples of their work in the learning process. During this work, the students generate definitions for the concepts by describing them from their own viewpoints.

It was disclosed many different approaches that students apply when representing the similar sets of concepts. Basing on a review of the students' maps, the following commonly occurring situations have been identified:

- students often insert superfluous nodes between related concepts;
- the same nodes of the map hierarchy are often moved to different positions in a hierarchical tree;
- one and the same node is frequently represented by one student as the major concept while another considers it as the subsidiary concept;
- a particular node in one map may match many nodes in the other one in the maps built by different students;
- students commonly provide different links between the same nodes, hence reflecting different understanding of these relations.

It was found as well that concept mapping without training is very problematic for students that are usually unable to structure and integrate the information in a proper way. Following (Roy, 2008; Marshall & Madhusudan, 2004), to produce a favourable outcome we consider training as a key factor. When concept maps can be easy explained to learners, we arranged training and map construction at the same time. The students were not asking to generate maps on the computer. During the training, they prepared the small hand-written maps suitable for easy reading. We agree with (Peters, 2005) that concept mapping can be introduced to the classroom with relative ease. From five to 15 minutes of the concept map training may be easily fitted into nearly any schedule. Consequently, we ranged the time to grade maps from three to 10 minutes, which appeared not more time consuming than multiple-choice quizzes or short essays.

As a result, our experience has shown how the concept mapping improves students' understanding of the material acquired from the class and how they make connections between the class and prior concepts. Mapping reinforces knowledge integration providing the learners with an activity, which promotes such integration. As far as the students enhance their understanding, they find more evidence in their knowledge area. Thanks to described dynamic nature of learning, the individual concept maps might never be complete (Bozhko & Heinrich, 2011). Concept mapping promote also many discussions, particularly if they are placed onto the screen and students see them. Finally, the maps help to find where and when the students need additional instruction.

5 Concept Maps as an Assessment Tool

A further strength of concept maps is their important role in assessment (Gouli et al., 2005). Concept maps are a valuable tool of assessment procedures because they evidently represent learners' knowledge through multiple feedbacks tailored to students' personal characteristics and requests.

It is difficult to assess what every student knows in a broad subject area. An important feature of concept maps is that they tend to be unique for each student. It is well known that human minds are highly different, especially, when they come to interpretations such as quality or completeness. As it has been reported in (Calafate, Cano & Manzoni, 2009), different people would construct different concept maps, even if they answer the same question and share the same level of expertise. Such uniqueness prevents an instructor from doing a quick evaluation since the estimated object is not right or wrong, but rather more complex, elaborate, and precise in direct relation to the students' understanding of the addressed domain. Therefore, the assessment process is prone to be complex, time-consuming and, in general, includes a strong degree of subjectivism, which should be mitigated (Stockwella, Smithb & Wilesa, 2009). The subjectivity appears when the teachers ask the concept maps they constructed for the same knowledge expressed in their lecture or textbooks.

To meet the challenge, it was found in (Roy, 2008) how to assess student's possibility in extracting quantitative and qualitative information about the studied material. In (Calafate, Cano & Manzoni, 2009), partitioning of the assessment process has been proposed using the steps followed for their creating as well as objective metrics that assign every step. Some authors scored the maps along several dimensions, including their comprehensiveness, the number of details, and the complexity of the links.

We have found that the concept maps as an assessment tool require consideration of as minimum two issues:

- how the maps are designed;
- how they are interpreted.

Effectiveness of these two issues have resulted in two approaches we used to compare the learner's maps with the expert's ones (Turns et al., 2000; Gouli et al., 2005). At the former, student-generated concepts approach, the maps collect the concepts and links a student identifies relatively to an evaluated domain. Every student constructs his map either directly or indirectly, with the help of an instructor who implements the learner's idea. The strength of this method is that emphasis is done on the understanding how a particular student appreciates a separate domain. Individual differences of student's understanding can be captured here. However, as the concept maps resulting from this method can be large, complicated, and difficult to interpret, it is usually problematic to provide a final judgment about a student's knowledge. In the second method, called an externally generated concepts approach, the assessment represents a quantitative comparison between two concept maps − the student's and the teacher's maps. Following this result, a map is interpreted by determining similarity between these two maps. The referent map might be constructed by a tutor based on his/her own knowledge or a map constructed to represent key knowledge in a textbook. The measure of similarity between the two maps displays the level of the student's knowledge.

The maps submitted by the students are usually quite diverse (Turns et al., 2000). A couple of such examples from our practice are shown in Figure 2. Three groups of the second-course bachelor students (about 60) were asked to build the concept map of the rectifiers studied in a series of lectures, exercises, and labs. The focus problem of mapping was to demonstrate the learners' ability to systematize their knowledge obtained from different sources, such as class lessons, own experience, textbooks and tutorials, Internet, peer-to-peer communications, etc. The examples show that the learners demonstrate different understanding of the concept relations, ranking, linking, and nodding. Some of learners resemble the maps that have been created during the classroom work. Such maps generally receive rather low scores on the comprehensiveness, detailing level, and complexity dimensions. To receive higher grade, the map should represent a large number of concepts, their cross-links, and hierarchy layers thus showing that the student can differentiate the elements of the domain. The volume of meaningful links contributes to the score significantly.

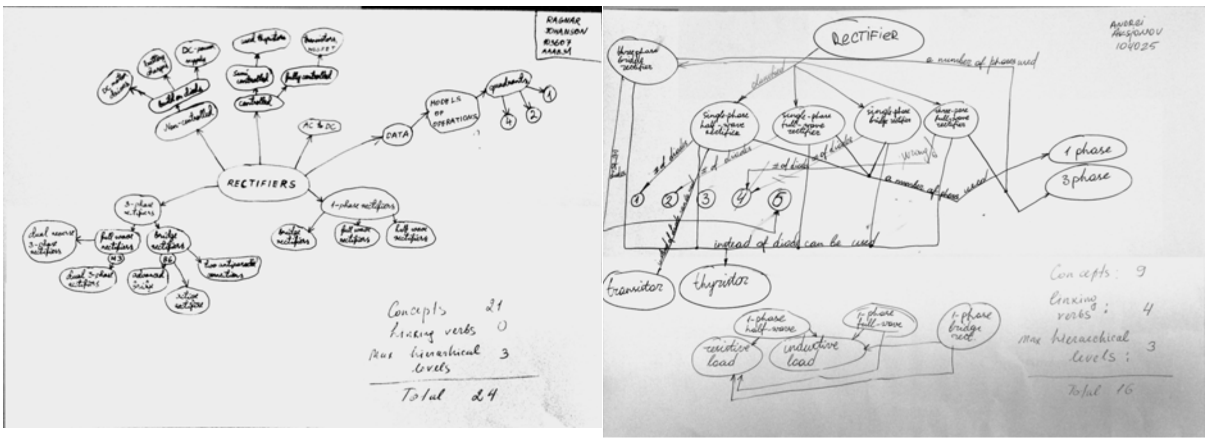

Figure 2. Students' concept maps.

The map interpretation usually covers both the quantitative scoring and the qualitative judgments on the appropriateness of the assessed model. In our assessment procedure, the final grade involves scoring the student's maps along such dimensions as the number of concepts, links, hierarchy levels, and examples. These scoring data stem from the concept mapping goals representing such features as breadth, depth, and connectivity. In addition to the scoring along these dimensions, the maps are commonly inspected for the number of invalid positions as well as the absence of major concepts and relations. During the assessment, every dimension is scored on a scale from zero to five.

The distribution of scores obtained in our experimentations argues that most of the students can reach rather high ratings. This suggests that by the end of the course, most of the students have acquired the concepts that they learned. For the volume of the acquired details, most of students have received the middle-level scores. This proves differences in the students' possibility to realise detailed concept description. The scoring distribution for concept connectivity has the greatest variation thus showing the difference between the students who learned carefully and those who were less successful in systematic learning.

6 Summary

It is shown that both the educators and the students have difficulty in development and interpreting the concept maps in Electronics as well as in establishing relationships between the concepts and entities. Being rather complex and time-consuming task, concept mapping requires considerable efforts in determination the major concepts and relations. The proposed study opens the useful ways for both the educators and the students in concept mapping application. The recommendations are presented how to get better results in Electronics comprehension and assessment. It is shown also that thanks to its process-oriented nature, concept mapping enlarges opportunities in success in all learning processes. Of course, the concept maps cannot be the only instrument because they represent a part of the full educational process. Usually they require much time to interpret and can remain ambiguous. They do not guarantee that the students are able to apply the concepts in design or other authentic engineering activities.

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