Teaching, Learning, and Assessment in Electronics
Using Concept Mapping Technology

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Abstract: The paper presents a study of the concept mapping informational technology for instruction in Electronics. As the first step of the ontology design, the authors have developed an effective descriptive model in the form of educational thesauri. Then, to represent the knowledge structure for meaningful education, concept mapping was introduced as graphic ontology for Electronics. Concept maps help students to see what they acquired from the class and support in making connections between new and prior concepts. This technique reinforces knowledge integration by providing students with an activity that promotes such integration. Also, it supports assessment procedures providing an explicit and overt representation of learners’ knowledge, informative, and reflective feedbacks tailored to learners’ individual characteristics and needs.

Key-Words - Informational technology; engineering education; electronics; concept mapping

1 Introduction
Today, many institutions seek better ways to enhance their educational technologies which, according to the UNESCO documents, should provide novel organisational arrangements for creation, application, and defining teaching and learning processes and resources with their interaction. The main objectives are to arrange high-quality education that motivates students to learn not only the skills directly related to their speciality, but also the additional knowledge domains valuable in the professional working environment. Knowing how and what students learn is important for judging the appropriateness of existing learning objectives and deciding how to modify instruction.

Commonly, students start their training in Electronics from the basic concepts through an introductory Electronics course and continue their education through the Power Electronics course. However, both the students and the instructors face with many problems in these courses [1]. Educators commonly expect students to find for themselves relations between the concepts they learn in Electronics courses and the topics they learn across other courses in the curriculum. In so doing, teachers rely on the novel informational technologies such as Web portals, databases, tutorials, and social networks that enable students to access large volumes of learning materials [2]. As a result, the teaching staff is often disappointed when students cannot make expected links as it often leads learners to an information overload [3]. Without proper experience, the students come across scrappy and fragmentary data being easily disorientated and unable to construct complete and systematic knowledge in Electronics.

Because of the diversity of the concepts provided for the curriculum, it is very difficult for the students to acquire a comprehensive picture of Electronics, Power Electronics, Electrical Engineering, and other domains. Similarly, it is difficult for the tutors to prepare the course content in an integrated manner at the students’ level. Additionally, the perception of the theory and practice behind the hardware and software topics and their connections is not an easy task for the bachelor students. Moreover, some of the topics are mainly abstract, therefore inapplicable to laboratory sessions. Students usually find those courses difficult to understand, which decreases their motivation about learning and success of the course. In [4], the same reasons were indicated with regard to other engineering disciplines.

Many studies concentrate on the methods of increased appreciation for large volumes of information. Traditional curricula management has become inappropriate both for educators and students who need continuous enhancing of their professional knowledge. To overcome such restrictions, some novel approaches have been
developed in the global educational practice, such as a “curriculum container” [5] and a knowledge representative “conceptual graph” [6] that elaborate the storing technique having stronger influence on the syllabi content rather than on the curriculum topology.

Researches [3], [7], [8] suggested that graphical form of studying material can reduce the problems of information overload and disorientation for learners. One of the most powerful graphical tools is represented by the concept mapping technology.

An interest to concept mapping stems from its interconnection with the memory and learning theories [9]. The central premise of semantic memory theory is that knowledge is stored in a network format by connecting the concepts to each other. The more tightly the knowledge representation is linked, the more likely is that a learner will recall information at the appropriate time. As a learner attains new knowledge through a process of integrating new knowledge with existing one [10], a network representation shows the integration of different concepts. This theoretical base has resulted in practical approaches used in concept mapping including semantic networks and knowledge maps. It was shown in [11] that concept maps can scaffold learners to understand novelties by mapping the relations among new topics and learned domains.

First suggested in [12], [13], concept maps serve as graphical representations of knowledge composed of concepts and the relationships between them. Since then, the concept maps were applied in a variety of educational fields, including instruction, learning, curriculum development, and assessment in mechanical, chemical, and computer engineering across a wide range of applications [14], [15]. They provide a useful reference for teachers to design adaptive courses and for learners to understand the whole picture of the studied knowledge domain. Researchers have used concept map representations to communicate information and as tools to support the design.

Different ways were proposed to generate common knowledge and to share information. Some studies, for example [16], have found how collaborative concept mapping improves students’ interaction and allows them to know about their classmates. Depending on the learning domain, the mapping based collaborative techniques have been implemented for organisation of the activities [17], interaction (synchronous, asynchronous or both), and management [18].

Among the concept mapping instruments, the toolbox CmapTools plays an important role [19]. Today, CmapTools are broadly used in engineering activity because of their focus on procedural knowledge and product interface design. Along with them, some other identical concept-based graphic tools are applied that differ in the way they focus on concepts, their relationships, and their structural and functional roles.

This work aims to show the approaches found for improvement and refining the educational strategy in Electronics. The next part of the paper represents a thesaurus methodology suitable for identifying the relevant concepts in multiple sources of knowledge and storing the learning objects linked to these concepts. In the third section, the concept maps were selected as tools that can help students in understanding all the Electronics knowledge domains and in making connections between concepts. In the following parts, concept maps are used as an effective tool to elicit a student's understanding of studied topics both before and after instruction. They demonstrate how the status of a particular concept in Electronics can possibly be influenced by statuses of other concepts thus giving learners adaptive guidance for the course understanding.

2 Educational Thesauri in Electronics

Similar to other disciplines of an educational curriculum, Electronics can be presented from an ontology perspective as a knowledge domain in which a set of concepts and the relationships among those concepts collected for the purpose of knowledge sharing and reuse accomplish ontology [20]. It is a goal of instructors to design their own ontology or to apply ontologies created by authorities in Electronics (domain experts) and to develop a syllabus in a way that reduces information overload and learning disorientation. Besides, instructors also use ontology to prepare teaching materials and to propose learning paths for guiding students [21]. To represent ontologies and to transmit them from a teacher to learner, descriptive and graphic models are discussed commonly [22].

As the first step of the Electronics ontology design, the authors of this paper have developed an effective descriptive model in the form of educational thesauri [23], [24]. In [3] the procedure of knowledge transfer was divided between information retrieval, concept items extraction, search of key concepts, and evaluation of “relation strength”. Following this procedure, many concepts were chosen from multiple sources as candidates to be included to an educational thesaurus in Electronics. Such concepts proposed by different
The first problem when creating a set of the concept maps that describes the domain of Electronics was to discriminate the most meaningful concepts from the less important ones to make them the basis of the concept maps created. Thus, the first step taken by the authors was to determine which concepts are the most essential, those that the student should not obviate. The second step of concept map creation was to link the concepts involved to construct a meaningful information structure. Thus, a network was designed consisting of nodes (points, vertices) as concepts and links (arcs, edges) as the relations between concepts, such as “is a”, “related to”, “part of”. Besides these two steps, there are other quality details that appeal the map designer’s dedication and interest in creating the concept maps, including segregating of the most important concepts from the rest through highlighting (fonts, colours, shapes, etc.), representative icons and figures, and connecting to outside web pages, applications, or other concept maps. The maps also include the cross-links representing the relationships between concepts of different sub-domains. Cross-links show how a concept in one sub-domain displayed on the map is related to a concept in other sub-domain.

As, according to the Novak’s definition [30], simplicity is the first important instructor’s requirement, a core question of the particular lesson commonly comprises no more than 25 concepts. Since the concept set of Electronics is too large, several sub-domains were organised for those who use the particular concept maps. The same way was applied for chapters and for parts of the courses.

Concept maps of different instructors are subjective because every concept map represents the author’s own knowledge and skill. In an educational context, a teacher wants to infer the student’s understanding and perspective on a topic. He also wants that the student concept maps would be represented by different resources in the same way that is, using the same words. This requirement affects concept mapping in two ways: (1) the terms for the concepts and relations are always extracted from some educational thesaurus; (2) the hierarchy reflects the importance of the concepts presented in the particular sub-domain. Therefore, the concept maps have become the suitable tool to support teachers in preparing their learning material content thus improving transfer of knowledge.

4 Learning with Concept Mapping

Similarly to [31], in this study the concept maps were used for learning purposes in two ways:

3 Teaching with Concept Mapping

The syllabi of the Electronics courses include lectures, laboratory works, exercises, homework, and assessments. The program follows a regular structure of engineering classes, such as two hours of lecturing and one hour of weekly exercises and laboratory works, plus the final exam at the end of the semester [29].

To represent the knowledge structure for meaningful learning, concept mapping was introduced as graphic ontology for Electronics along with the educational thesauri. The Electronics concept map arrangement comprises four sub-domains interconnected by the cross-links, namely “Semiconductor Devices”, “Electronic Components”, “Analogue Electronics”, and “Pulse and Digital Electronics”. In the same way, the graphic concept maps were developed for representation of the knowledge models and associated resources of the Power Electronics science domain. The concept maps based on the Power Electronics thesaurus comprise six sub-domains interconnected by the cross-links, namely “Introduction”, “Rectifiers”, “Inverters”, “AC/AC Converters”, “DC/DC Converters”, and “Utility Circuits”.

authors were not always consistent as they often described the same concepts using similar terms but not exactly the same ones. Therefore, these terms were primarily classified by the thesauri designers into appropriate groups to reduce their total number. The next our step was to summarise the large datasets by removing informational redundancy aiming to find the key concepts. At last, their interconnection was decided. In the simplest case, a linear topology without loops and minimal concept linking was proposed. However, many concepts have complex relationship whereas some of them have no interconnections with other concepts within the domain and such decoupling was minimised.

The final thesauri created to store these grouped terms became the very useful tools from the educational viewpoint [25], [26], [27]. They accompany many electronic documents of the disciplines related to Electronics instruction. Using interactive hyperlinks, educational thesauri clarify and explain the meaning of concepts through other learning materials, such as lectures and practical guidelines [28]. This hierarchically structured interactive dictionary interprets now about 1000 concepts in the Electronics domain of knowledge. Each of its entries has a semantic (meaningful) relationship with the preliminarily given definitions.

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In both approaches the aim of concept mapping was to stimulate learners’ personal understanding, to draw them into creation of individual examples against the existing theoretical and practical tasks, and to improve the students’ learning outcomes.

Following to [32], for the maps created in the classroom, mapping time was usually restricted by 5 to 20 minutes. On the contrary, if mapping is specified for the homework, learners were asked to derive information from numerous resources, such as books, Internet, and other digital media libraries. Information gathered could be useful in the course evaluation and in the simplification of knowledge comprehension.

It is a remarkable feature of the described approach that a significant volume of the mapping resources is optional. This stimulates the strong students in their success in learning. At the same time, the weak students acquire mainly the mandatory information presented in the textbooks and manuals. Such technique promotes deep understanding and development of conceptual knowledge acquisition, motivates introduction of international syllabi, proceeds joint curricula design in collaboration with foreign universities, ensures preparedness for instruction in English, attracts international students in the bachelor’s and master’s programs, opens broader opportunities for students to take up studies at other recognised universities, and fosters flexible training techniques.

The experiments have shown that it is not a trivial task for learners to organise and identify the main thematic topics. Therefore, students should study multiple learning objects and make notes in their concept maps that personalised learning and re-enforced it thus increasing skills and promising knowledge distribution among the participants.

As it was mentioned above, the hierarchical nature of the concept map allows the concept organisation from the high abstract level to more specific layers. This property was used by students for managing and structuring data in development of relations for the concepts that form their concept maps. Moving thought the curriculum they learned to understand given concepts, to recognise the proposed examples, and to define the concepts from their viewpoints.

Students used many different approaches when representing the same sets of concepts. Based on a review of the students’ maps, several commonly occurring situations were identified, earlier predicted in [33], such as excess/missing elements, organisational variations, cross-links, and granularity and cardinality differences.

Concept mapping without training would be very problematic for students as they might not be able to structure and integrate the information in a proper way [8]. Because concept maps are easy to explain to students, training and map construction were performed in our practice at the same time. In the classroom the maps were commonly hand-written whereas the homemade concept maps were generated within the computer CmapTools environment.

Our experience has shown that concept map development helps students to understand what they have acquired from the class and to make connections between class concepts and prior concepts. These maps reinforce knowledge integration by providing students with an activity that promotes such integration. Concept maps stimulate also discussion, particularly when the maps are placed onto the screen and students discuss them. Finally, the maps provide guidance on where students need additional instruction.

5 Assessment with Concept Mapping
A further strength of concept maps is the value beyond their role in assessment. Thanks to above shown benefits, the concept maps are considered to be a valuable tool of assessment procedures as they can indicate what students are actually learning and how they do it [34].

Assessing what every student knows in a broad subject area is difficult. It has been reported in [35] that different people would construct different concept maps even if they answer the same question and share the same level of expertise because human mind is highly different, especially when it comes to interpretations such as quality or completeness. Therefore, the evaluation process is prone to be complex, time-consuming and, in general, includes a strong degree of subjectivism, which should be mitigated [36].

An important feature of concept maps developed by our students is that they tend to be unique for each learner. Such uniqueness prevents us from doing a quick evaluation since the estimated object is not right or wrong, being more complex, elaborate and precise in direct relation to the student’s understanding of the addressed domain. The subjectivity appears when we ask the concept maps the learners constructed for the same knowledge expressed in their lecture or textbooks.
In accordance with recommendations of [8], [35], we tried to extract quantitative and qualitative information about the assessed topic. Two issues were taken into consideration: how the maps were designed and how they were interpreted? Perspectives on addressing these two related issues have resulted in two methods, both of which were accomplished by comparing the learner’s map with the expert’s one. At the former approach, called in [9] a student-generated concepts approach, the assessed maps have represented the collection of concepts and relations a student identifies relatively to an evaluated domain. They were constructed either directly by a learner or indirectly by an instructor based on the learner’s ideas. The strength of this approach is that emphasis is placed on understanding how a particular student interprets a learning domain. Individual differences as either concepts or links that are or are not included were captured here. However, as the concept maps resulting from this method were normally large, complicated, and difficult to interpret, it was problematic to provide a final judgment about a student’s knowledge. At the second method called in [34] externally-generated concepts approach, the assessment represents a quantitative comparison between two concept maps – the student’s map and the teacher’s one. Following from this result, the interpretation of a map was performed by determining the similarity between these two maps, the measure of which stated the grade of the student’s knowledge.

The maps submitted by the students are commonly quite diverse. Some of them resemble the maps created during the classroom activity. Such maps generally received low scores on the comprehensiveness, level of detail, and complexity scoring dimensions. The highest grades were given to the maps having a large volume of concepts, connections, and an extensive hierarchy between the concepts showing that the student can differentiate between the levels in describing the elements of the topic. The large number of meaningful cross-links contributes to a high rating for link complexity because the cross-links appear primarily within clusters of concepts in the middle and lower levels of the map.

To interpret the maps, both the quantitative scoring and the qualitative judgments on the appropriateness of the teacher’s model were used. The assessment involves scoring the student’s concept map along a variety of dimensions such as number of concepts, number of links, number of cross-links, number of hierarchy levels, and number of examples. These scoring data represent characteristic features of knowledge such as breadth, depth, and connectedness. They stem from the theoretical motivations for concept maps including the analytical notions of categories, differentiation, and coordination. In addition to scoring along these dimensions, the maps were inspected for the number of invalid propositions as well as the absence of critical concepts and links. To complete the grading, each of the dimensions was scored on a scale from zero to five.

Distribution of scores assigned for concept comprehensiveness shows that most of the students receive high ratings. This suggests that the students as a whole seem aware of the concepts that they had learned. The distribution of scores for the level of details shows that more students receive the middle-level scores. This suggests differences in the students’ abilities to provide detailed description of concepts. Finally, the scoring distribution for link complexity displays the greatest variation. This shows that a key to distinguishing among the students who learned carefully and those who were less successful may be the ability to see complex connections between the different topics.

The results of the analyses of the students’ assessments can have implications for refining learning objectives, improving instructional strategies, identifying appropriate assessment tools, and understanding how the learning objectives are being realised by students. They provide an explicit and overt representation of learners’ knowledge and promote meaningful learning thus supporting the learning process and providing different informative, tutoring and reflective feedbacks tailored to learners’ individual characteristics and needs.

6 Conclusion
Our research in the Electronics domain has shown that educators and students experienced in concept mapping produce better results in the course comprehension and presentation than those who cannot construct the concept maps. Thanks to its dynamic and process-oriented nature, concept mapping enlarges students’ opportunity to engage in the learning process.

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