Concept Mapping and Concept Modules for Web-Based and CD-ROM-Based RF and Microwave Education

K. C. Gupta, *Fellow, IEEE*, Ramesh Ramadoss, and Huantong Zhang

***Abstract*—This paper suggests the use of concept mapping and an approach for the use of concept modules as primary-learning units for Web-based and CD-ROM-based RF and microwave education. A brief discussion on the notion of concepts relates them to the assimilation theory of education. The role of concept mapping in the learning process is emphasized. A generic structure for proposed concept modules is discussed. Examples are included to illustrate the approach. For a detailed case study, a hyperlink to a companion tutorial article in this TRANSACTIONS is provided in the electronic version of this paper. Advantages of the proposed approach for a Web-based asynchronous learning environment are highlighted.**

***Index Terms*—Concept maps, concept modules, Web-based tutorials.**

I. Process of Learning

THE key function of Web-based or CD-ROM-based tutorials is to facilitate self-learning. In the process of self-learning, the learner must choose to learn meaningfully, that is to relate new knowledge to the knowledge the learner already knows. The meaningful learning is the key element in education. According to Novak [1], the theory of education may be summarized very briefly by saying that: "Meaningful learning underlies the constructive integration of thinking, feeling and acting; leading to empowerment for commitment and responsibility." In addition to the relationship to prior knowledge, the quality of meaningful learning is also dependent on the conceptual richness of the new material to be learned. On the other extreme, the *rote* learning occurs when the learner memorizes new information without relating it to the prior knowledge, or when learning the material that has no relationship to prior knowledge.

Assimilation theory of meaningful learning was introduced by Ausubel *et al.* [2]. He is one of the pioneers who helped to move the educational psychology away from behavioral models of learning (based largely on animal studies from the 1930s to 1960s) to cognitive models that focus on how humans construct new meanings and use knowledge in creative problem solving.

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This paper has supplementary downloadable material available at http://ieeexplore.ieee.org, provided by the authors. This includes a hyperlinked companion tutorial article to illustrate the approach. This material is 5.4 MB in size.

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Concepts

Concepts constitute an important aspect of assimilation theory of learning because comprehension and meaningful problem solving largely depend on the availability (in the learner's cognitive structure) of both higher (superordinate) concepts (in subsumptive or detailed concept acquisition) and lower (subordinate) concepts (in superordinate concept acquisition). This is based on the fact that human beings interpret all "raw" perceptual experiences in terms of particular concepts already present in the cognitive structures in their brains. It is also known that concepts constitute the building blocks both for the meaningful reception learning of propositions and for the generation of meaningful problem-solving propositions.

What exactly is a concept? A concept may be explained [2] as an object, event, situation, or property that possess common criterial attributes (despite diversity along other dimensions or attributes) and is designated by some sign or symbol, typically a word with generic meaning. Novak [1] defines a concept as a perceived regularity in events or objects, or records of events or objects, designated by a label. For example, "electric field" is a concept. This concept is subordinate to the concept of "field," which encompasses the concepts of gravitational field, magnetic field, etc. in addition to the concept of the electric field itself.

Concept acquisition or learning may be defined as the process of learning the meaning of a concept, i.e., learning the meaning of its criterial attributes. This learning process includes the process of concept formation (by a semi-inductive process of discovering the criterial attributes from multiple particular examples of the concept) and/or the process of concept assimilation (by reception learning of the new concept meaning when presented with the concept's criterial attributes by definition or context). Fig. 1 illustrates "concepts" and their relationships to propositions, to concept maps, and to the attainment of knowledge in a graphical representation. Continuing with our example of the concept of "electric field," a learner may be introduced to the attributes of the electric field; namely, an electric field is said to be present at a location if an electric charge placed at that point experiences a force. Thus, in order to learn the concept of electric field, one's already existing cognitive structure needs to include the concepts of "electric charge" and "force." The understanding of the relationship between "electric charge" and the "force" experienced by a charge is the process of learning the concept of "electric field." Interplay between these concepts is illustrated graphically in Fig. 2. The relationships among the concepts constitute the key step in the learning or educational process.

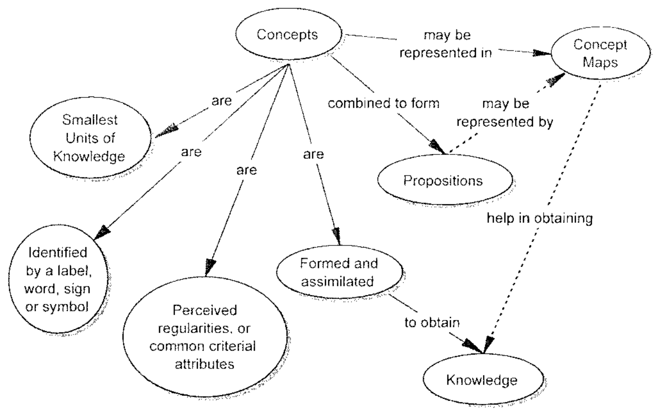

Fig. 1. Relationships among concepts, propositions, concept maps, and attainment of knowledge. These relationships play a key role in assimilation theory of learning.

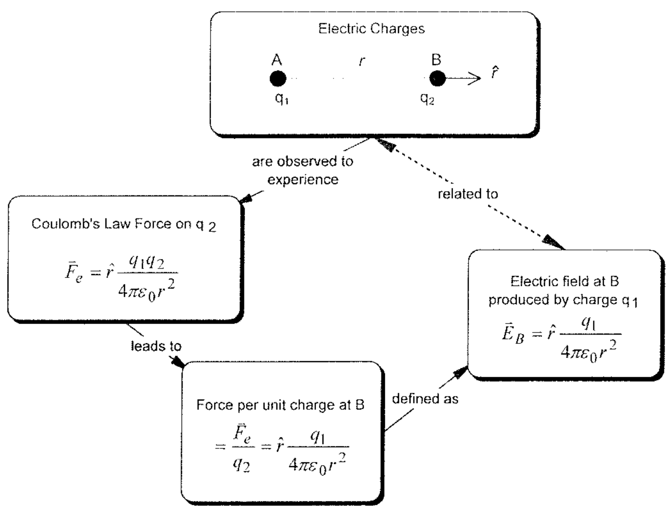

Fig. 2. Relationships among the concepts of electric charge, force, and electric field. Understanding of such relationships among concepts constitute the process of learning.

II. Concept Mapping

A concept map is a graphical display that illustrates a set of concepts in a particular field or domain and relationship between those concepts. In science and technology domains, concept mapping consists of sequential and rational development of involved and complex-looking concepts from simpler concepts developed earlier. According to Novak [3], concept maps are tools for organizing and representing knowledge. Knowledge construction represents meaningful learning built through the organization of concepts and propositions. Propositions contain concepts and other words combined to form meaningful statements. For example, the statement, "*electric field* is the *force* experienced by a unit *charge*" is a proposition linking the concepts of electric field, force, and charge. Fig. 2, which illustrates the relationships among the concepts of electric charge, force, and field, is an example of a concept map. As pointed out earlier, cognitive learning is the process of assimilating new concepts into existing cognitive structures. These concepts and structures are represented visually through the process of developing concept maps. The concept map in Fig. 2 helps in understanding the concept of "electric field" by linking it to the concepts of

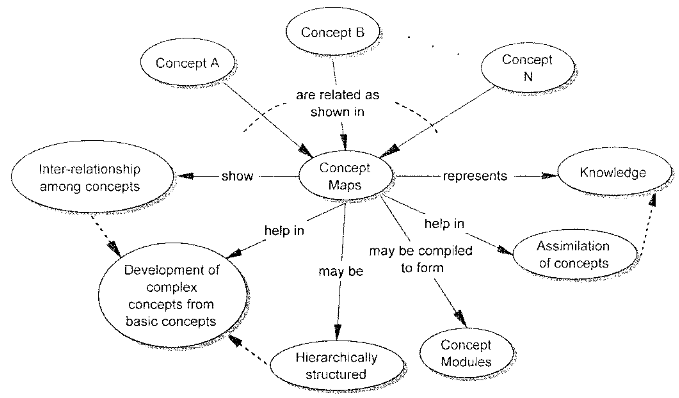

Fig. 3. Concept map illustrating the notion of concept maps.

charge and force that are already present in the cognitive structure of the learner.

Typically, concept maps have the following characteristics [3]:

- concepts are represented as a hierarchy, with the most general concepts at the top of the map and the most specific below;
- cross-links showing how the concepts in different parts of the representation are related;
- specific examples used to clarify the meaning of a concept.

In other words, an abstract concept may be defined in more specific terms through examples of that concept. Not every scholar on concept maps would agree on the suggestion that concept maps be hierarchical. This is particularly true for those who stress the use of concept maps for encouraging creativity, where unusual juxtaposition of concepts may show novel cross relationships. In physical sciences and technology, sequential and rational development of involved and complex looking concepts from simpler concepts developed earlier often dictates the flow in a concept map. Jonassen *et al.* [4] emphasize the hierarchies are not the only method of construction for concept maps. Jonassen *et al.* [5] explain that concept maps are an illustration of "structural knowledge" or how the concepts within a particular domain are related. Concept maps help learners to link new information to what they already know. This is based on the assumption that structural knowledge is necessary for both understanding and problem solving, which is certainly true for physical sciences and technology domains. A concept map illustrating the notion of concept maps is shown in Fig. 3. Relationships among different concepts labeled A, B, ..., N can be depicted graphically by one or more concept maps. These maps may illustrate the development of complex concepts from basic concepts, and may be structured hierarchically. These maps help in assimilation of new concepts and are thus representation of knowledge. A number of concept maps may be clustered together to form concept modules.

Another example of concept mapping related to the analysis of transmission lines (used extensively at RF and microwave frequencies) is shown in Fig. 4. This representation starts with three concepts that the learner is expected to know from previous experience and learning. These are: A—transmission-line characteristic impedance Z_0; B—load impedance Z_L; and C—superposition of waves traveling in two directions.

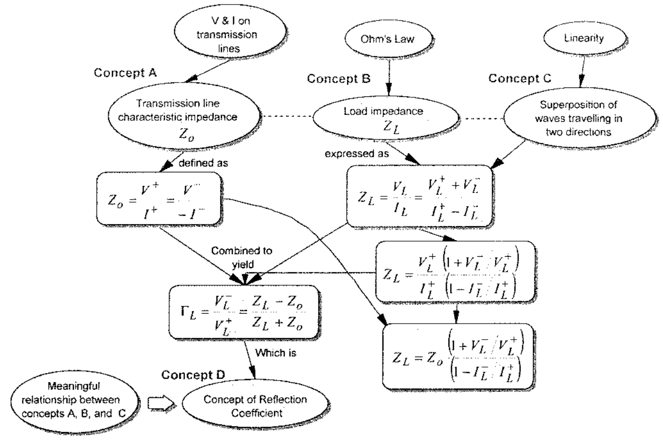

Fig. 4. Development of the concept of reflection coefficient from concepts of: A) transmission line characteristic impedance, B) load impedance definition, and C) superposition of waves.

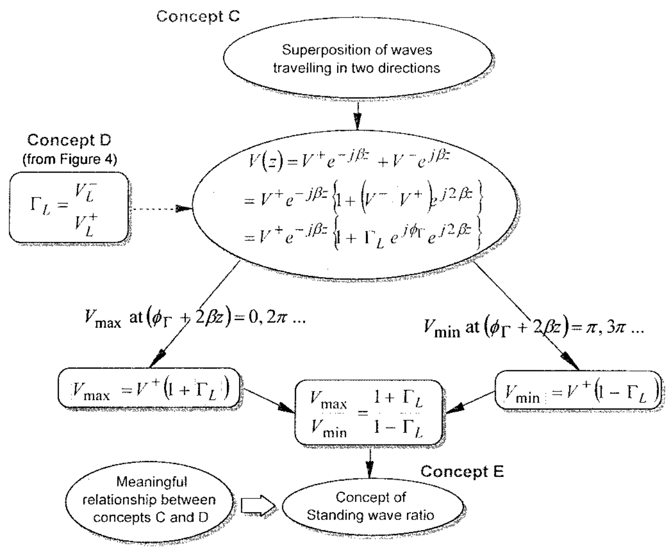

Fig. 5. Development of the concept of standing-wave ratio from the concepts of reflection coefficient and superposition of waves.

This map shows that meaningful relationships among concepts A–C bring out the meaning of reflection coefficient Γ_L (concept D in the map) in Fig. 4. An extension of this concept mapping sequence (shown in Fig. 5) develops a meaningful relationship among concept of reflection coefficient (concept D) and superposition of waves traveling in two directions (concept C) to bring out the concept of standing-wave ratio (concept E in Fig. 5). These examples show how the relationships among concepts help us in learning new meanings.

Advantages of the concept-mapping approach are summarized in Fig. 6. Concept maps express the meaning embedded in a framework of proposition, and this expression of the meaning helps in recognition and/or development of new relationships among concepts. Thus concept maps play a critical role in the learning process. Some specific tasks that are actuated by concept maps and are useful in the learning process include: 1) grasping meanings; 2) reflective thinking; 3) recognition of missing links among concepts; 4) negotiating meanings; and 5) fostering creativity.

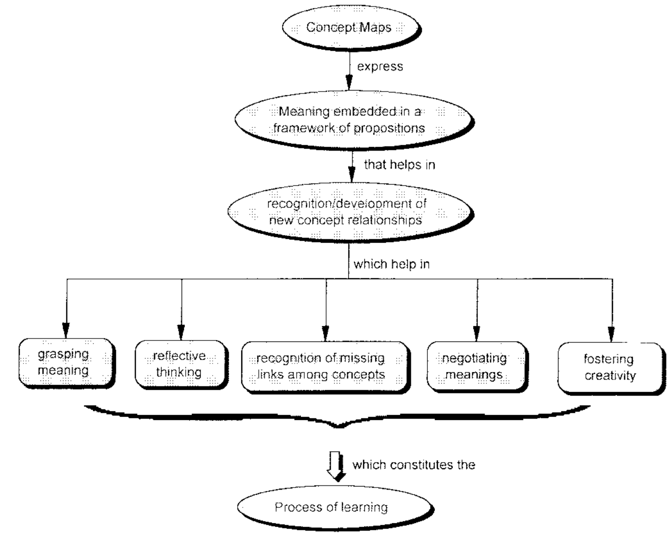

Fig. 6. Role of concept maps in the process of learning.

The basic idea of concept maps is very similar to the mind-mapping approach [6], which is recognized to be an exciting way of using and improving memory, concentration, and creativity in planning and structuring thoughts on all levels in order to accelerate ability to learn, remember, and record information. There has been a very limited use of concept mapping at students' learning level. The only widespread example is in the field of biology [7]. However, microwave education (for that matter, teaching and learning in any domain) could benefit immensely by application of the concept-mapping approach. A number of software tools, such as *Inspiration*,[1] are commercially available for drafting concept maps similar to the figures in this paper. These facilitate the graphic portion of constructing concept maps and concept modules.

III. Concept Modules

A concept module may be defined as a set of related and interlinked concept maps put together to help learners to build up expertise in a specific topic. For example, scattering parameters is an important topic in RF and microwave engineering. The scattering parameters (or S-parameters, as they are commonly known) are widely used for representation or characterization of RF and microwave networks. A discussion on S-parameters can be presented in the form of a concept module. Contents of such a concept module would consist of several concepts maps. Fig. 7 shows various subtopics under the heading of S-parameters for which concept maps will be needed. Each of these subtopics may need one or more than one concept map for explaining the concepts involved. Of course, selection of these subtopics (and of the concept maps included in each of these subtopics) is a somewhat subjective decision by the instructor responsible for the development of the tutorial. A companion paper in this Transactions presents this concept module on S-parameters as a part of tutorial on "RF and Microwave Network Characterization—A Concept-Map-Based Tutorial" [11].

The idea of dividing a specific domain of knowledge (say, microwave engineering) into a number of interconnected concept

[1] *Inspiration, ver. 6.0*, Inspiration Software Inc. Portland, OR, 2000. [Online]. Available: http://www.inspiration.com

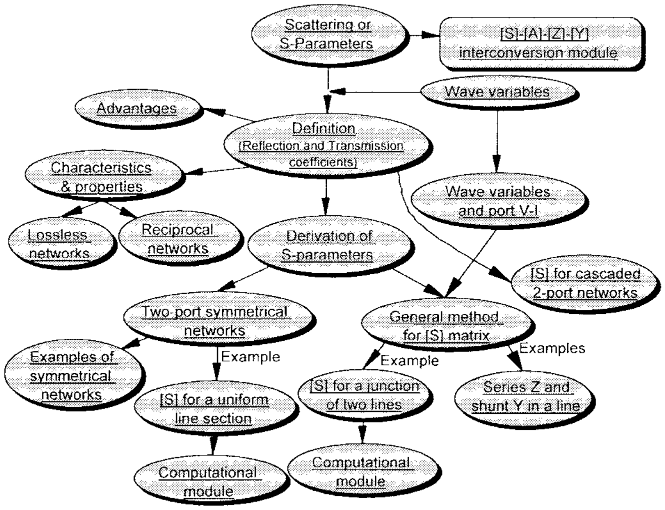

Fig. 7. Contents of a concept module on S-parameters. Each of the sub-topics shown may need one or more interlinked concept maps for illustrating various concepts involved.

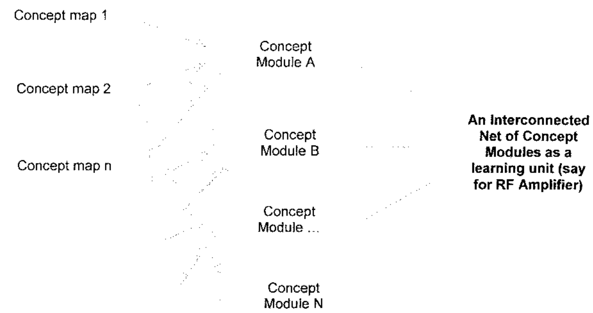

Fig. 8. Simple architecture showing relationships between concept maps, concept modules, and learning units in any discipline.

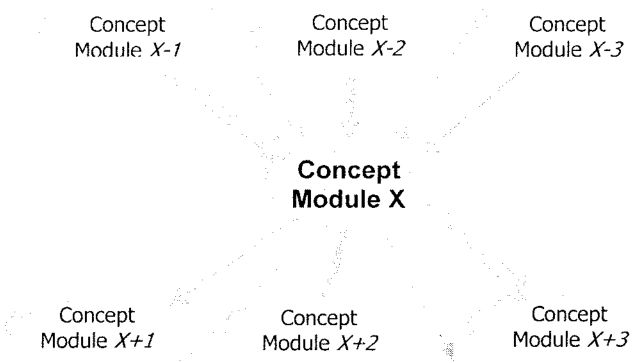

Fig. 9. Linking among concept modules. A basic concept module X, which depends on the concept module $X-1$, $X-2$, and $X-3$, is needed to proceed to the concept modules $X+1$, $X+2$, and $X+3$.

modules is very appropriate for Web-based or CD-ROM-based distance education or self-learning. In our traditional educational system, most of the educational programs (leading to various degrees, diplomas, certificates, etc.) are divided into a preselected number of courses. Each of these courses runs over a prespecified duration of time (15-16 weeks for a semester, three months for a quarter, etc.). Often, some lower level courses are considered as prerequisites for registering to take higher level courses. This structure, with minor variations, has been successfully used for several decades.

As we move toward a learner-oriented self-paced asynchronous system for higher and continuing education, the traditional course-based curriculum structure needs to be examined for its efficiency. Quite often, it is seen that all of the semester-long contents for the courses (say, A and B) listed as prerequisites for another course (say, C) are not required for learning the contents of the course C. One may need only a part of the course A and only a part of the course B to learn and accomplish the objectives of the course C. When each of these courses is divided into primary concept modules, one needs to learn only the concept modules of courses A and B that are prerequisite for learning the concept modules of the course C. When a learner wants to use the knowledge in the course C to the project at hand immediately, such a modular approach is more efficient.

Based on the simple idea mentioned above, one could restructure various courses into primary concept modules and interlinking of these modules to reflect the logical development of knowledge in the domain of the discipline being studied. The two steps in this process, the segmentation of the knowledge domain into interlinked modules and the development of each of such modules, can be based on the concept-mapping approach.

Fig. 8 shows a simple architecture for concept maps and concept modules that is particularly useful in the technical and scientific areas we are dealing with. A combination of interconnected concept maps constitutes a concept module; and an appropriately interlinked combination of concept modules becomes a learning unit (say, for RF and microwave network characterization, as described in [11], or for an RF amplifier design). Note that a single concept map can be shared (that is hyperlinked to) by a number of concept modules, and a single concept module can be a part of several learning units. This reconfigurability of concept maps and modules is very useful for a flexible design of teaching and learning plans.

Thus, a concept module is a well-defined step in the development of the domain knowledge. Each concept module is based on and drawn from one or more of the concept modules developed earlier and prerequisite for the subject being studied. Fig. 9 shows the generic relationship diagram for a concept module X that depends on at least three other modules labeled as $X-1$, $X-2$, and $X-3$. That is, knowledge contained in concept modules $X-1$, $X-2$, and $X-3$ is needed before one can learn the concept module X. Two other incoming dotted lines show dependence on two other modules not shown in the figure. Outgoing relationships to concept modules$X+1$, $X+2$, and $X+3$ imply that the knowledge of the module X is needed for understanding of modules $X+1$, etc. Thus, the concept module structures (similar to the one shown in Fig. 9) show the logical development and flow of the concepts of the domain knowledge.

The basic instructional structure of a concept module consists of various items required for learning the knowledge embedded in the concept module. These include a quick review of the prerequisite modules by answering a few selected questions based on each of the earlier modules. If responses to these questions are not satisfactory, the learner is advised to go back to the specific prerequisite modules for a refresher. The key step in learning the concept module X is the use of the knowledge in

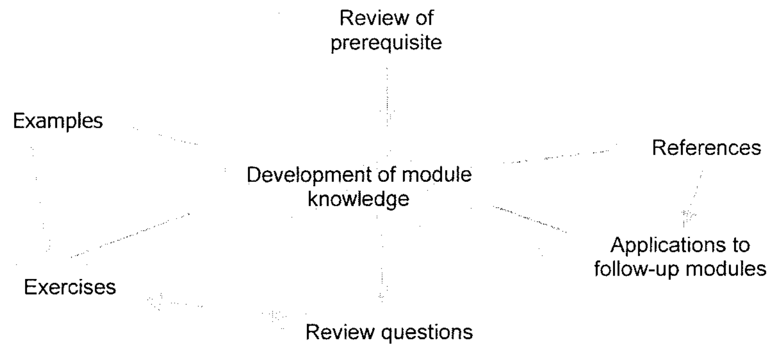

Fig. 10. Some of the ingredients of a well-designed concept module. Note that the features shown here are also well-known characteristics of any other good learning medium.

the prerequisite modules to derive (or arrive at) the knowledge represented by the module X. This is reinforced by adding in the module examples of the knowledge in X, exercises, review questions, related references, and applications of the knowledge in X to the follow-up concept modules ($X+1$, $X+2$, and $X+3$ for the structure shown in Fig. 9). These key ingredients of a typical concept module are shown in Fig. 10. These components, namely, examples, exercises, review questions, references, and further applications, are also desirable components of all other good teaching and learning methods (including the conventional classroom instruction). Arrows show the interrelationship among these ingredients. For example, we note that examples should precede exercises, review questions and exercises complement each other, and the references should include pointers to follow-up modules.

IV. Advantages of the Proposed Approach

There are several pedagogic advantages in using the approach of concept mapping and concept modules in teaching and learning, particularly as we emphasize self-learning in continuing education. Major advantages are discussed here. The concept map in Fig. 11 shows these advantages, which may be enumerated as follows.

1) *Clarity*: A graphical representation in the form of concept maps brings out clarity in logical development of the theme without being overwhelmed by complicated mathematical details quite common in engineering disciplines.
2) *Interrelationships among concepts*: Division of knowledge in concept modules and use of concept maps points out vividly the relationships among different concepts. This recognition of interdependence among concepts helps in identifying crucial steps in understanding the theme.
3) *Hierarchical overview*: Related to the above-mentioned point on interrelationships, concept mapping is also useful for a convenient representation of a hierarchical overview of the domain knowledge.
4) *Missing links among concepts*: Layout of concept maps also helps us to recognize any missing links among the concepts in any body of knowledge. This aids in identifying topics for further exploration and research.

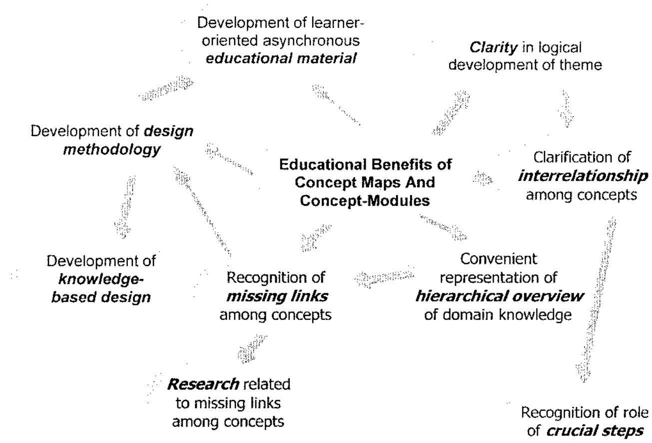

Fig. 11. Educational benefits of concept mapping and concept modules. It is a powerful approach for developing technology-based learning materials for higher and continuing education.

5) *Development of design methodology*: This is especially applicable to knowledge in engineering domains.

Once the logical development of concepts is clearly represented, we can use this mapping structure for development of design procedures. Need for developing automated design procedures leading to knowledge-based design has been recognized in microwave/millimeter-wave engineering domains [8].

Perhaps the most outstanding and timely application of the concept mapping and concept modules is in the development of educational materials [9]. Keeping abreast of the current trends in higher and continuing education [10] calls for development of Web-based and CD-ROM-based student-oriented modules for self-paced learning. We can look forward to accelerated developments in this area.

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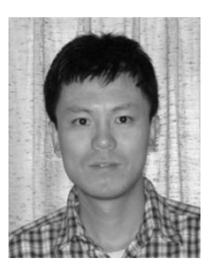

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