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Promotion of Transfer of Knowledge and Skill Through Hypermedia-Assisted Comprehensive Self-Study Procedures*

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This paper explores a method for facilitating the development through hypermedia-assisted comprehensive self-study procedures in electrical engineering of the key ability in students to *transfer* knowledge and skill from a known to a dissimilar context. The organisation of the content material, which is based on cognitive science and modern pedagogical theories, plays a critical role in the development of these procedures, and the combination of instructional approaches adopted provides a reliable basis for achieving the learning objectives. The knowledge base is structured as a generic model for the embedding of learning and teaching strategies and can be tailored for diverse applications. The integrated model presented in this paper shows a considerable consistency which will greatly contribute to the promotion of transfer of knowledge and skill through hypermedia technology.

INTRODUCTION

Promoting transfer of knowledge and skill has long been a central topic in engineering education. Many innovations in teaching have been introduced to promote the transfer process, placing new requirements on computer assisted instruction (CAI) systems. The challenge that CAI designers face is how to integrate learning theories, pedagogical strategies and contemporary technology appropriately and effectively in order to unlock the potential for such technology to supplement teaching in terms of transfer of knowledge and skill.

Interest in the use of hypermedia as a supplement to existing teaching approaches has flourished in academia in recent years with the blooming of hypermedia technology. Many educational delivery systems have been developed in a wide range of subjects with the emphasis on exploring the learning potential of advanced technology. Despite the practical and theoretical significance of the technology however there is little consensus about how best to promote transfer of knowledge and skill.

The main purpose of this work is to explore the possibility of facilitating the development of the key ability in students to transfer knowledge and skill from a known to a dissimilar context through hypermedia-assisted comprehensive self-study procedures in electrical engineering. As the major determinant of transfer is the way in which the subject material is organised and taught, the subject material is firstly analysed with regard to the following three criteria: content organisation, sequencing strategies and instructional approaches, all based on cognitive science and instructional design theories [1]. The hypermedia knowledge base is designed as a generic model for embedding learning and teaching strategies to tailor particular applications. With embedded strategies, namely Vee heuristic at macro level, concept map and algorithm procedure at micro level, the knowledge base provides a problem-oriented learning environment for students to acquire and utilise knowledge and skill [2]. The integration of content material and hypermedia knowledge base forms a hypermedia-assisted learning system which can significantly contribute to the promotion of transfer of knowledge and skill.

TRANSFER OF KNOWLEDGE AND SKILL

In general, transfer of knowledge and skill is *the ability to draw on or access one's intellectual resources in situations where those resource may be relevant* [3]. Learning is managed and instituted in order to establish this skill of *transferability* in the individual [4].

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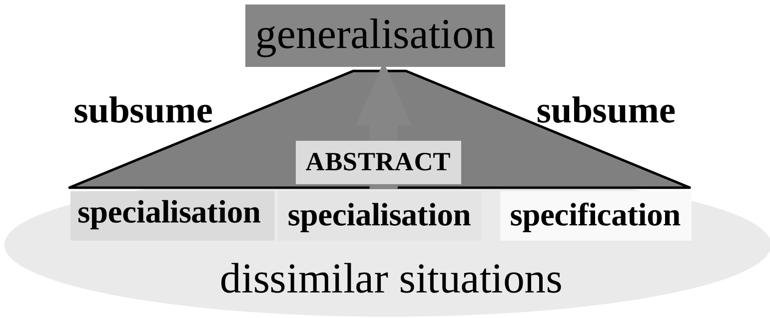

Figure 1: The relationship between generalisation and specification.

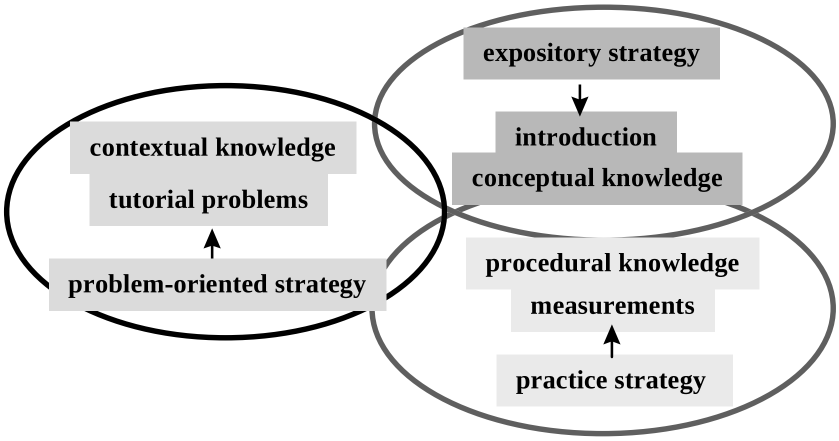

Figure 2: The organisation of the content material.

There are two kinds of transfer that have been emphasised by educators. One, called *vertical transfer,* is an effect of the acquisition of further knowledge at a higher level; the other, called *lateral transfer,* concerns the transfer of learned capabilities to novel and practical situations at roughly the same *level of complexity*. Both kinds of transfer are of importance in education [4]. Essential conditions for transferability of acquired knowledge are generalisation and specification, which together constitute a universal law of cognition. Our understanding of the world around us develops from the particular (concrete concepts and objects for example) to the general; we then apply the general to other specific situations. Generalisation is abstracted from specification, but subsumes specifications at a higher level so that it is more inclusive and has a wider significance in dissimilar situations (Figure 1). As T. Nowacki says:

> *The intellectual tasks and problems usually have a* skeletal *character, therefore the formal dispositions and structures could have more universal applications. Practical situations (problems) have even more complex relations and structures from which a specific one has to be selected* [quoted in 5].

This is why procedural knowledge that is conceptually understood is more likely to be accessed when needed, because conceptual knowledge frees up the procedure from the surface context in which it was learned and facilitates its transfer to other structurally similar problems [3]. Transfer is more likely to occur therefore when students are able to see what they have learned as a generalisation which can be used in a wide variety of situations and, at the same time, are able to discriminate the specifications in a new situation where generalisation may be inapplicable.

Transfer may be influenced by many factors at different levels, such as the organisation of the knowledge, the pedagogical and instructional strategies embedded in the teaching material, the richness of the learning environment and so on. At the level of knowledge organisation, for example, the richness of the connections between the components of knowledge is the important factor. At the strategy level, the awareness of knowledge, or metacognition, is considered the paramount factor; whereas problem-orientation is regarded as the sound approach to promoting the knowledge transfer at the learning environment level. In view of the benefits of such a technique, this transfer of knowledge and skill should be promoted to teachers for use in their professional practice.

APPROACHES EMPLOYED IN THE CONTENT MATERIAL TO FACILITATE TRANSFER

Transfer of knowledge does not take place automatically. No subject or learning material by itself assures transfer. The major determinant of transfer appears to be the way in which the subject material is organised and taught [1].

The comprehensive self-study procedures used in this research have been designed on the basis of a novel educational model which employs recent advances in modern psychology and educational theories. By following the procedures presented in the teaching/learning material, students are able to analyse the problems (problem-oriented strategy), identify important concepts and principles (conceptual knowledge), determine which laboratory procedure has to be adopted (procedural knowledge), verify their lessons by setting up experiments (experimental strategy), and interpret the experimental results and write laboratory report (acquire awareness) [2].

Keeping in mind the factors which influence transfer of knowledge and skill, the teaching material has been examined from the angles of content organisation, sequencing strategy and instructional approaches.

Content organisation

Subject content organisation is the basic factor affecting knowledge transfer. The better the organisation of the content material, the better the accessibility [3].

The book which forms the basis of this work, *Basic Electrical Engineering: Laboratory and Tutorial Procedures* (the book from this point onwards), including the comprehensive self-study procedures, is structured in eleven compact methodological units, each of which consists of five parts: objective, introduction, measurement procedures, tutorial problems and recommended references [6]. Each part deals with different types of knowledge respectively, with emphasis being placed on procedural knowledge.

The introductions contain major declarative knowledge, including concepts, indispensable notions, laws and principles. The measurement procedures allow students to gain procedural knowledge by carrying out experiments. The tutorial problems are oriented for the development of cognitive skills embedded in the algorithmic procedures, which facilitate solutions. The recommended textbooks help students to find comprehensive information concerning particular problems. The design of the material is consistent with, and supported by, this effective knowledge organisation and hence provides a basis for the integration of different instructional strategies. These strategies include the expository strategy for learning the declarative knowledge in the instructions; practice strategy for learning the objective of intellectual skills by doing things; and problem-oriented strategy, which presents problem situations that require establishing cognitive strategies for retrieving and employing appropriate knowledge (Figure 2).

Layer-nested sequencing strategy

The sequence of subject matter content influences the stability of cognitive structures and thereby influences long-term retention and transfer [7]. In the literature of instructional design technology, Reigeluth and Curtis categorise four sequencing strategies: Brune's *spiral sequence approach*, Ausubel's *general-to-detail sequence*, Reigeluth's, as we call it, *layers elaboration*, and Gangé's *parts-whole relationship* [7]. These four major types of sequences are variations of the simple-to-complex sequence pattern which differ depending on the content type's orientation and desired learning objectives (that is verbal information, intellectual skills and cognitive strategies), each focusing on one type content, while the others become supportive only.

The design of the self-study procedures under discussion features three *layer-nested sequence strategies* as shown in Figure 3. The first layer is a *parts-whole* sequence, the second strategy is a *specification-to-generalisation* strategy, and the third is *simple-to-complex*.

There are distinctive two *parts-whole* relationship modules in the material. In the first *parts-whole* module the components of the simple circuit, such as a voltage, a current and a resistor, are introduced in Units 1, 2 and 3, which relate to Ohm's Law and Kirchhoff's Laws which are discussed in Units 4 and 5. This implies that in order to confirm the laws by experiment, the components have to be measured first. This can therefore be regarded as Gangé's *parts-whole relationship* strategy dealing with steps and sub-steps of a procedure at a physical level. The second *parts-whole* module includes Units 6, 7 and 8, which deal with individual circuit components, whereas Units 9 and 10 combine circuit elements with physical phenomena.

The second layer is more like Ausubel's *specific-to-generalisation sequence,* which deals with conceptual knowledge at a logical level. For example, Units 1, 2 and 3 in the book deal with specific concepts of electrical circuit theory, such as dc current, voltage, resistance etc. Ohm's Law, Kirchoff's Laws

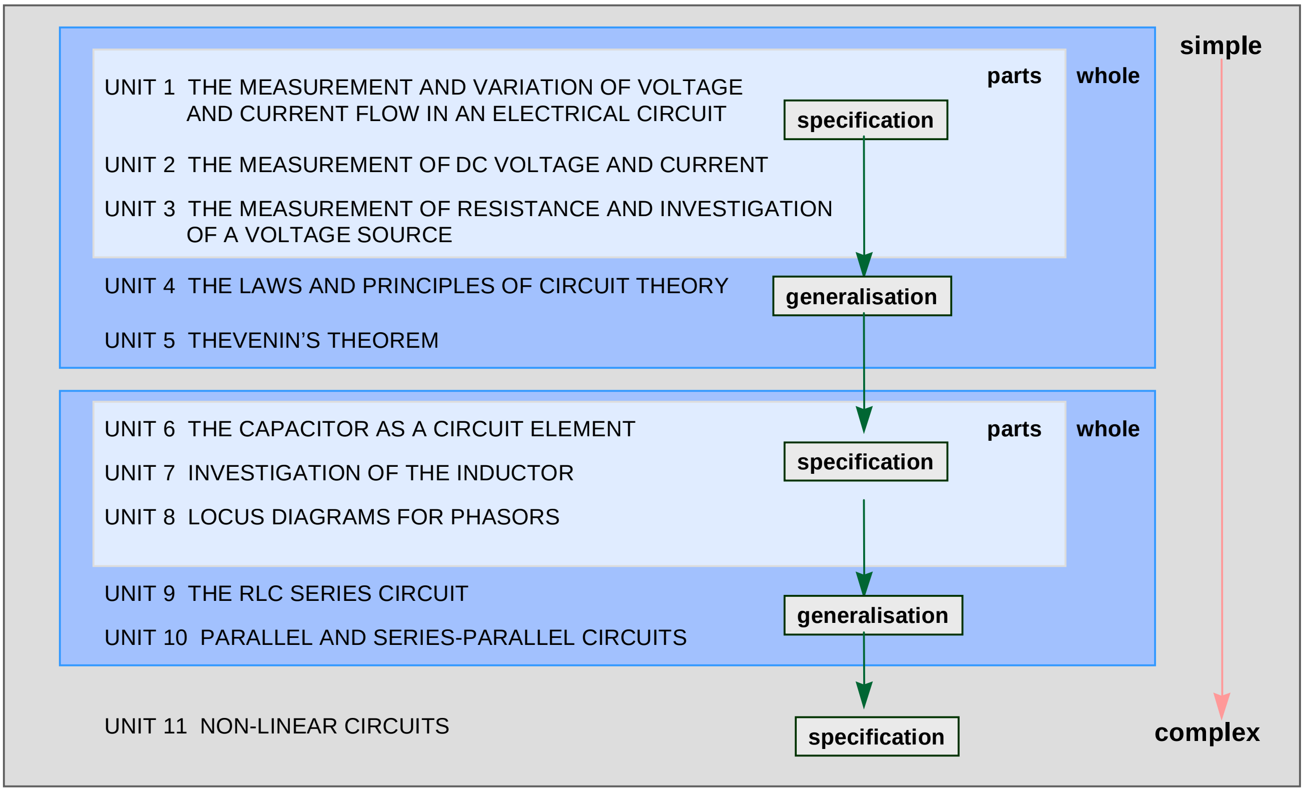

Figure 3: The layer-nested sequencing strategies of the content material.

and some other principles are then discussed in Units 4 and 5. The more general concepts and principles subsume the specific concepts and reveal their relationships, and can thereby be used in dissimilar problem-solving situations. Units 6, 7 and 8 introduce other circuit elements with specific attributes. Students must be able to apply the general laws and principles to the circuits consisting of those specific elements, and must be able to discriminate those specific instances of the simple circuit. The same applies to Units 6 to 10.

This sequence strategy is significant in promoting transfer of knowledge as each cycle of the cognitive process of *specification-to-generalisation* promotes the knowledge to a higher perception level, which then indicates a deeper understanding of the concept.

The entire structure of the book follows the third *simple-to-complex* strategy, where simple linear circuits are treated first, followed by more complex circuits, including non-linear circuit components in the last unit (Unit 11).

The objective behind the design of the book was to foster a correct way of thinking by embedding effective thinking strategies in logical sequences to be carried out in classroom instruction. From the learning system design point of view however, it is necessary to consider how to maintain the *layer-nested sequence strategy* because it involves the issue of learner control. With non-linear hypermedia technology, students tend to be given more flexible access to the learning materials, especially to self-study material. This may cause the loss of the intended sequencing strategies. How to maintain the thinking strategy effectively in a hypermedia-assisted system and how much freedom should be given to students in accessing the learning material are therefore critical issues for system designers. Their position on these issues is highly dependent on the educational goals and the learning objectives expected from the system. Pointing out to students the learning objectives, relationships between the units and the sequencing strategies may be an effective approach to enhancing their awareness, thereby promoting transfer of knowledge and skill.

INSTRUCTIONAL APPROACHES

The algorithmic procedure

Transfer of knowledge is strongly influenced by how effectively one thinks about cognitive strategies which can be performed at a goal-oriented level. Students need to be given the opportunity to think in order to be able to develop relevant cognitive strategies; that is, they must be trained *how to think* [8]. This can be achieved by the proper presentation of the problem. As mentioned earlier, one of the significant characteristics of the book is the design of a variety of algorithmic procedures.

In the book the structure of an algorithmic procedure typically consists of the description of a situation and performance objectives, followed by a step by step procedure. Some are simple procedures and some are complex procedures with some questions involved in the logical steps. The questions employed in the procedure create a situation in which students are required to think *what* should be done, and *why,* in the process of acquiring procedural knowledge by either solving the theoretical problems or experimenting in the laboratory. This implies that some cognitive strategies will be used by students in a natural way, meaning that students may not necessarily realise that they have been conditioned to perform these strategies.

Obviously the cognitive strategies used by subject matter experts, such as *backward chaining* and *generalisation* etc, are embedded in the algorithmic procedures. By following the procedures, students gradually develop a correct way of thinking and doing, thereby developing the knowledge, skill and professional habits required for their future jobs. It is quite common that even simple strategies that are obvious to the teacher are not always apparent to the student, so that an explicit description of the strategies, and information about the benefits of the strategies, are more likely to assist the development of student awareness with regard to transfer.

Question-answer solution strategy

From the point of view of transfer of knowledge, learners' awareness of their own knowledge status can be seen as a prerequisite for getting them to consciously reorganise or restructure their knowledge. Such an awareness can not be obtained substantially without making oral and written statements [2]. In accordance with the *question-answer-solution strategy* the procedures in the book can be seen as a step forward in this direction. They require students to write their answers freely by providing them with a blank space for recording their answers. The book also provides students with the opportunity to evaluate their achievements by giving sample solutions. This *question-answer-solution* process is partially uncontrollable in the book, which means the order through which the students' expressions are recorded and presented relies heavily on their learning styles, confidence and responsibility. Obviously students can cheat by copying the solutions provided, and they may obtain a high mark for their work. Of course if students want to cheat, they cheat themselves of an education which in the future would not warrant professional success. Although the assessment process appears not to be extremely reliable, the author has made a conscious decision to challenge the honesty of students. By taking advantage of hypermedia technology, free access to the sample solutions can be denied or controlled. It will be the personal choice of an individual lecturer to provide students with access to the solutions without penalising them for the occasional use.

Strategies embedded in the knowledge base to promote transfer

The primary underlying philosophy for the hypermedia knowledge base design is that the physical knowledge base should function as an extension of the storage subsystem in cognitive memory, allowing a learner to use their memory's retrieval system to access both cognitive and physical knowledge bases. The hypermedia knowledge base is designed therefore as a generic model for the embedding of learning and teaching strategies, such as Vee heuristic and concept map, and can thus be tailored to diverse applications [2].

In the design of a hypermedia knowledge base, several approaches are adopted with the intention of facilitating transfer of knowledge and skill in students. The strategies can be divided into two levels [2]. At the macro level, the hypermedia knowledge base has a multifaceted structure consistent with the cognitive knowledge base system. In addition, an effective pedagogical strategy, Vee heuristic, is combined for promoting the knowledge awareness which is one of the most important factors influencing transfer. Two specific strategies at the micro level are *concept map* and *algorithmic procedure*. The *concept map* is considered an effective tool for fostering the elicitation and acquisition of conceptual knowledge, while the *algorithmic procedure* is used to create a practical situation in which the student learns how to apply theoretical knowledge correctly to solve problems.

MACRO-LEVEL STRATEGIES

Knowledge base consistent with cognitive memory

Knowledge organisation is the basic factor affecting knowledge transfer [3]. The better the organisation of the knowledge base, the better is accessibility. Thus the first step towards promoting transfer is determining the components and structure of the hypermedia knowledge base.

The organisation of the knowledge base is attributed to its elements and connections. According to cognitive science, the semantic networks can be categorised into three types of knowledge: declarative (knowing what), procedural (knowing how) and contextual knowledge (knowing when and why). The types of knowledge possess different characteristics for learning, storage, recall and transfer. One effective way of organisation is therefore to classify the knowledge into different types, and then to synthesise and present them accordingly. This may greatly facilitate the acquisition, employment and transfer of knowledge and skill [2].

The basic structure and organisation of the hypermedia knowledge base contains five to seven types of knowledge, depending on the subject domain [9]. The conceptual knowledge includes concepts, principles or rules. Procedural knowledge consists of process, procedure or methodology. Contextual knowledge includes the criteria, values, and appropriateness of a given domain's schematic structure. It refers to an understanding of knowing when and why to use conceptual and procedural knowledge in solving domain-specific problems. The contextual knowledge can be improved by presenting problem-solving situations: problems, cases, examples etc. Contextual knowledge thus glues together the other components in the knowledge base for better accessibility and transferability [2].

The value of the hypermedia knowledge base with knowledge types is the embedding of effective learning and teaching strategies in a broader range, such as Ausubel's conceptual learning theory, Novak's Vee heuristic, concept map and algorithmic procedure, as proposed in content material by Pudlowski.

Vee heuristic device as interplay between knowledge acquisition and knowledge construction

Accessibility to relevant knowledge in dissimilar situations is a function of the transfer of learning. The access to knowledge is thought to be fostered when students are made more aware of what they know and do not know about a subject; developing such awareness is viewed therefore as one important way to enhance knowledge transfer [3].

From a knowledge construction point of view, learners' awareness of their own knowledge state can be seen as the prerequisite for getting them to consciously reorganise or restructure their knowledge. This is consistent with the ideas behind an effective pedagogical strategy, Vee heuristic, proposed by Novak and Grown in their book *Learning how to learn* [10]. Vee mapping, which deals with the nature of knowledge and the nature of learning in a complementary fashion, is a sound approach to helping learners recognise the interplay between their previous knowledge and the new knowledge they are attempting to construct [3]. The two sides of the Vee are interdependent and represent the interplay between conceptual-thinking-theoretical elements (on the left-hand side) and procedural-doing-methodological elements (on the right-hand side).

This strategy promotes the two aspects of the process of transfer of knowledge and skill from the two sides and one point [2]. From the left-hand side, the approach is to make students more aware of their own conceptual knowledge state, facilitated by concept map strategy; from the right-hand side, the approach is to provide facilities for students to gain procedural knowledge by doing. Each time the Vee focuses a problem or analogical problem situation, it puts the learners and the two types of knowledge in a context. By analysing an analogical problem situation, students need to identify and employ the conceptual and procedural knowledge in both cognitive and physical intellectual resources in order to find the solutions in dissimilar situations. Therefore, one aspect of knowledge transfer, applying theoretical knowledge to practice, is promoted.

On the other hand, analysing solutions or results requires them to identify the associations of those concepts and principles with the problems and verify the conceptual knowledge they used, which assists them to become aware of the important concepts, principles or critical ideas in a given problem situation. Thus, the other aspect of transfer, awareness of theory in practice, is facilitated.

In addition, with the assistance of an analogical problem situation, students develop contextual knowledge concurrently, that is knowing when and why to select specific concepts, principles, procedures and methods in both the cognitive and physical knowledge bases. Students' ability to access and utilise their intellectual resources in potentially relevant situations is therefore fostered.

MICRO LEVEL STRATEGIES

Concept map visualisation of conceptual knowledge structure

In the knowledge base, organisation is equivalent to connectedness. The elaborateness or richness of the connections between knowledge components are the key factors which influence the accessibility of the knowledge base.

The concept map is viewed as an explicit method for eliciting knowledge structure from both experts and learners' cognitive storage system. It is also considered to be a powerful pedagogical strategy for allowing students to visualise their conceptual knowledge and, at the same time, to reveal their misconceptions. It is the awareness of the lack of understanding that forms the first step towards conceptual knowledge construction. In this sense, the concept map contributes to the approach that engages students in a process of constructing knowledge, therefore promoting the process of transfer of knowledge and skill.

Algorithmic procedure providing motivation to practise cognitive thinking strategies

Algorithmic strategy was widely used in early CAI systems which relied heavily on a step-by-step procedure in learning. In this strategy, instruction is offered with a relatively fixed sequence to lead the student through the procedure interactively. The algorithmic procedure can be linear or branching. In the linear structure the individual does not have to search for a solution procedure; it is part of the problem-solving schema that is automatically activated when a problem type is recognised. Transfer process is thus relatively static [3]. This algorithmic strategy is useful for developing procedural knowledge of certain subject matters in which problems may have one correct solution.

The branching structure encourages the learner to discover a variety of ways in which the problem may be solved [3]. In this case, students, when confronted by a problem situation in which they lack sufficient knowledge or understanding, have to frequently access cognitive and physical intellectual resources in order to reach a proper solution. Thus the approach to transfer is dynamic. This algorithm is more suitable for improving higher level cognitive skills of problem solving and creativity.

Distinguished from conceptual knowledge, procedural knowledge is more concerned with the carrying out of some action. It is characterised by a situation in which one knows what should be accomplished when confronted with a problem, but without having a clear idea about what series of actions are necessary to achieve it [3]. This type of knowledge is easier to obtain by following the algorithmic procedures.

Noticeably, algorithmic strategy may not be very effective without the problem orientation in the hypermedia knowledge base. It is the problems that put the task in a motivating context in which students are engaged in acquiring procedural knowledge actively and being aware of what they already know and the knowledge they need to learn to reach the solutions. For example, the algorithmic procedure motivates students by giving the sample solution in each step of the problem-solving procedure so that students acquire a clear understanding of the basic procedural knowledge without developing possible misconceptions. In addition, the similarity of the algorithmic procedure steps evokes positive transfer which can be defined as an influence on the results of learning, using knowledge and skill previously obtained [5].

AN INTEGRATION OF KNOWLEDGE BASE AND CONTENT MATERIAL TO CONTRIBUTE TO TRANSFER

As observed earlier, transfer of knowledge does not take place automatically, and no subject content material or a computer-assisted learning system by itself assures transfer [1]. The major determinant of transfer appears to be the way in which the learning material or learning system is organised . Therefore, to integrate the subject content material with the hypermedia knowledge base in this respect seems to be the most rational approach to promoting transfer. As discussed above, the integration can be easily reached as the designs of learning material and hypermedia knowledge base are all substantially based on cognitive science and educational theories. Figure 4 shows the concept model of hypermedia-assisted comprehensive self-study procedures.

In the model the same body of subject content is structured based on six types of knowledge and can be presented in different ways. The most basic knowledge types are concepts, principles and methods (classified from introductions of the content material) and procedures; the others are objectives, recommended texts, and equipment.

The Vee points to the tutorial problems, which creates a problem-oriented learning environment. In order to solve problems, the learners will be motivated to follow the procedures and find out the relevant conceptual knowledge. On the right-hand side of the Vee, the 11 measurement procedures are arranged based on the layer-nested sequencing strategy. On the left-hand side, the knowledge base uses concept mapping strategy to present conceptual knowledge. The cognitive structures of conceptual knowledge are represented visually. Each concept map contains five to seven concepts and each key concept is an anchor by taking advantage of hypermedia features. With the processing of the self-study procedures, learners' knowledge accumulates spirally, which is one of the major prerequisites for transfer of knowledge and skill. As the material in each unit is mastered, the knowl-

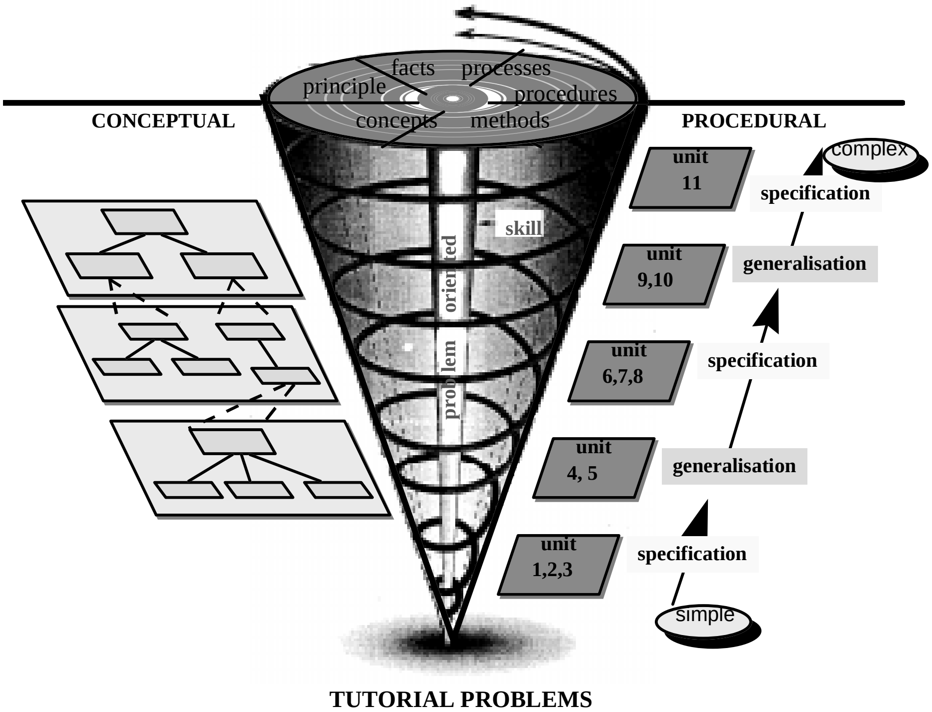

Figure 4: A concept model of hypermedia-assisted comprehensive self-study procedures.

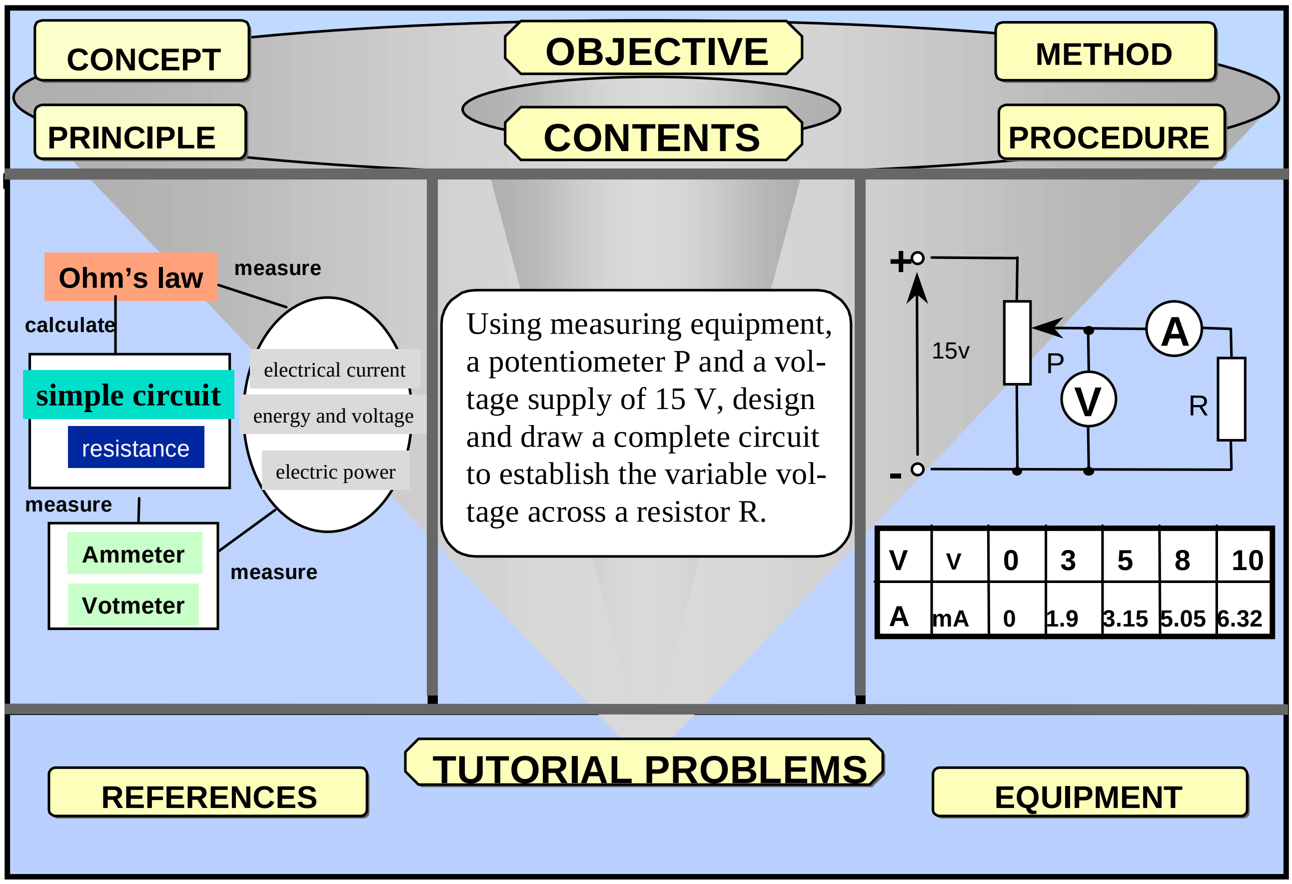

Figure 5: The layout of the hypermedia-assisted comprehensive self-study procedure system.

edge and skill in all previous units become prerequisites to begin the next unit. In each new unit, prerequisite knowledge should be elaborated upon by increasing the complexity.

Based on this concept model, an overall layout is presented in Figure 5 [2].

The master screen is divided into five frames. The up-frame contains major knowledge type linkages and navigation facilities. The contents of the concepts, principles and procedures will be shown in the middle frames correspondingly. The methods will be presented in a pop-up window.

The middle part consists of three frames. The left frame is used for presenting the concepts and principles in the form of concept maps and for responding to students' input. In the middle frame, problems are presented in the form of statements and diagrams. It can also pop-up a window for situation simulation or explanation. The right frame is for students to follow procedures to solve tutorial problems and receive immediate feedback for calculation and solutions. In addition, online explanatory annotations is provided for underlying concepts, and students can also input their own comments and reflections. The system provides means for the lecturer to collect student work and monitor their performance in laboratory experiments.

In the bottom-frame, there are buttons for references, tutorial problems and equipment choices. The references button provides students with recommendations by presenting reference page numbers in relation to the corresponding methodological unit contents. The equipment choice is a simulation of the laboratory environment, allowing students to perform experiments; combined with the tutorial problems, this creates a problem situation for developing contextual knowledge.

CONCLUSION

Proper technology should be used to supplement existing teaching methods; however, advanced technology cannot itself guarantee the enhancement of the teaching/learning process automatically without underpinning from both an educational and technical perspective.

No matter how sophisticated and comprehensive the software programmes are, the final product depends very much on the learning material. Therefore, content analysis based on cognitive science and modern pedagogical theories plays a critical role in this endeavour. In summary of the above content analysis, the design of the material combines the technical knowledge with modern educational psychology and instructional design. The integration of the strategies adopted in the procedures, such as the content type orientation, layer-nested sequencing and problem-solving algorithms, provides a reliable basis for achieving the educational goal, namely promoting transfer of knowledge and skill. The underlying assumption is that the content structures, sequence strategies and instructional approaches provide an important basis for the decision making process concerning the issue of how to select, sequence and synthesise the system components in the given subject matter when developing a hypermedia-assisted learning system.

Taking advantage of the hypermedia features and the knowledge base structure provides a generic framework for flexible organisation of subject structure and content. It can be used to combine the various pedagogical strategies, and can thus be tailored to diverse applications.

The development of hypermedia-assisted comprehensive self-study procedures described in this paper is an integration of the knowledge base and the content material for laboratory tutorials in electrical engineering. As the designs are all substantially based on cognitive science and educational theories, a seamless integration can be easily reached.

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BIOGRAPHY

Ms Shi Tao graduated from the XinJiang University, Urumuqi, China, with a Bachelor of Radio Engineering in 1979. From 1979 to 1993 she was a lecturer in the XinJiang Normal University, Uru-muqi, China. Presently she is a Master's student within the UNESCO International Centre for Engineering Education, Monash University, Melbourne, Australia.

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