Session: 3430, paper 727_

Development of a Modularized Co-constructivist Learning Environment for Electrotechnology

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Abstract

This paper outlines our POWERGUIDE project to develop a new computer based learning environment to help University and College students develop a deeper understanding of industrial Electrotechnology. This subject includes electromagnetic and electromechanical devices and systems as well as basic electrical power engineering principles. The computer-based software provides the students with an interactive constructivist learning environment. The students collaboratively construct their own understandings by exploring the effects of systematically changing parameters and configurations over a wide range of situations. This is possible because the software is designed to remove the drudgery of complex computations and to display the results in a clear and attractive graphical form. The software allows the instructor to assign thought-provoking activities, including design projects. Projects offer the opportunity for guided learning conversations among the project participants. The approach is based on an electronic workbook illustrating the basic concepts by means of practical examples taken from typical industrial plants. The electronic book also provides the students with the theoretical aspects of each device under study using hyperlinks. The software package selected as the backbone is the mathematical spreadsheet MathCad, because of its capabilities of handling technical mathematical problems as well as its advanced features such as hyper link and graphical abilities. The underlying electrical principles are exhibited by means of simulations of typical devices, such as three-phase loads, transformers, motors, and electronic loads. Formative evaluations are currently being conducted with college and university students and some results will be presented. This work is a contribution to instructional design and development methodology, as well as to electrical engineering education.

I. Introduction

The problems

Engineers and Technologists need to understand components and control deeply and in context in order to be able to deal with applied research and development of modern electrical systems and address new design challenges and requirements. Conventional instruction often seems to produce fragmented and mechanized knowledge that remains on superficial. Such inert surface knowledge is minimally transferable, and is an inadequate basis for the creative work needed in these rapidly evolving fields. Frequently the students have developed habits of just taking the textbook formulas or simple algorithms of a given chapter and applying them automatically to the set problems at the end of the chapter. This "task robot" behavior as Harri-Augstein and Thomas call it[1] got them through high school and introductory university courses. But it does not work for more complex problems in advanced courses, let alone those they will encounter in real industrial contexts. Another aspect of the situation is what Harri-Augstein et al.[1] have called "learning robots". Many students have developed the habitual approach to learning of just memorizing a collection of formulas, diagrams and algorithms. Whereas what is needed is a well-organized meta-cognitive self-management (planning, and execution-monitoring)strategy if they are ever to be able to generate deep coherent understandings of how specific techniques are derived from basic principles and contextual constraints(boundary conditions).

In addition, teaching in Engineering has come under pressure from the new technological environment and the new industry demands and constraints:

(a) "Just in time, just on topic" instruction is increasingly demanded by students and potential employers.

(b) Modularity and adaptability in the selection and organization of course topics are highly desirable.

(c) Breadth of knowledge is gradually replacing depth in areas that are fundamental engineering but have become general and complementary knowledge from the point of view of potential employers.

(d) The mathematics involved in most engineering topics is becoming increasingly complex, and there is often little time to instruct students in mathematics. Application of mathematical techniques is however necessary to produce meaningful results and to convey a better understanding of engineering subjects to students.

Electrical Engineering is now a discipline that is fast evolving, shifting from the traditional subjects, power engineering, electronics and communications, to a broad category of knowledge known as information technologies, and largely based on software technologies and applications.

Previous attempts at solutions

Many approaches using computer technology have been taken over the past thirty years to address these problems with limited success. Tutorial Computer Assisted Instruction (CAI) based on behaviorist learning theory - subdividing topics into tiny steps and providing intermittent positive reinforcement for evident success in those steps -, has proven effective in training for habitual skills. That approach makes the "task robot" problem worse; the skills so learned do not transfer horizontally to analogous tasks in different contexts, nor vertically to more abstract tasks.

Meta-cognitive regulative skills like planning and self-monitoring skills are needed for successful discovery and inquiry-based learning. Apart from being supportive for learning about the domain at hand, these metacognitive skills should also be seen as a learning goal in themselves, as they are needed in a wide variety of professional and technical situations. Therefore, during the use of simulations, the provision of scaffolding and guiding in metacognitive skills, as well as with respect to the subject matter itself is essential for the students construction of real active transferable understanding.

The guiding help -"scaffolding" should be gradually withdrawn as the student exhibits increasing capability to guide his/her own learning [3]. Multimedia learning support software is not free from the problems, which appeared with earlier forms of computer aided learning [4].

The proposed solution

AN ELECTRONIC WORKBOOK SYSTEM: **POWERGUIDE**

Computer-Based learning Support (especially cognitive scaffolding units) systems are being increasingly promoted as a means to enhance and enrich learning and teaching of concepts in all fields of exact sciences, particularly engineering. The objective of this project is to innovate in course delivery and create a new learning environment for Basic Electrical Engineering, including Power Engineering, topics. This is a compulsory subject for all Engineering students. The specific goal is to develop interactive instructional material that would replace large parts of the conventional textbooks and incorporate appropriate problem-solving software. The software package concept, that can be distributed as a CD-ROM or made available on the Web, allows integration of theory, enhanced using hypertext and hyperlinks, with examples worked out using embedded simulation software. The paperless textbook is developed using advanced mathematical spreadsheets, and eventually using authoring system software (Quest+, etc.). Advantages include flexibility and modularity, and use of the CD-textbook as workbook for students. The material is constructed so that it is very easy to publish / put up on Web-CT or Departmental course websites. The proposed learning support tools enhances student understanding of the course material and extends both their theoretical and practical knowledge.

II. Theory and contexts

For situated learning, two kinds of contexts need be considered. One is the context of use of the particular engineering subject matter. The other is the instructional system context.

INSTRUCTIONAL SYSTEM ***context: Eight Dimensions of the Instructional System***

Whenever one designs learning support, eight dimensions need to be considered. Prof. Helmar Frank [5] elucidated six and Gary Boyd added two more [6]. These are illustrated schematically in Figure 1.

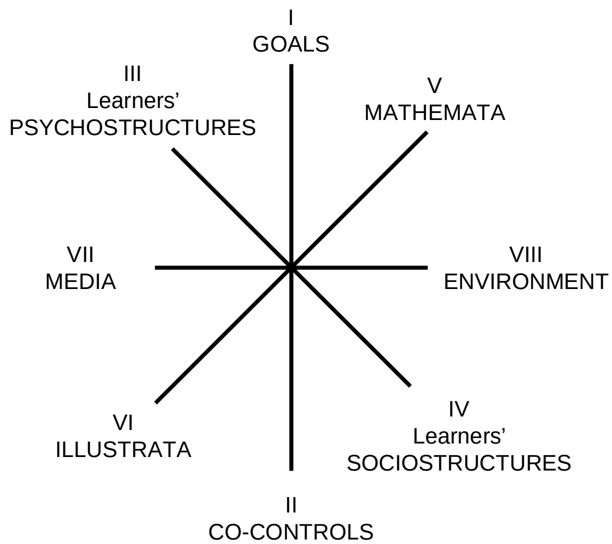

Fig. 1. Learning support system dimensions (based on Frank/Boyd)

All of the important parameters and variables in each of these four-paired sets of sets of variables have to be carefully considered and managed. They must be wisely chosen, carefully negotiated, be continually monitored and be formatively evaluated on an ongoing basis for success in the instructional system/subsystem development process.

III. More detailed description of the solution under development:

This section describes the 8-D schema applied to the Electrical Engineering Learning support system. Let us look at each of these classes of variables in turn in more detail to see how they need to be specified to teach topics in Basic Electrical Engineering and Electrotechnology education.

I - MANAGING ***GOALS***

In the case of the industrial electrical engineering curricula the general areas and the topics are clearly set out in the standard texts. The sequence of topics in POWERGUIDE is largely determined by the logical structure of the subject matter, basic concepts and components are used to build more complex and inter-related systems and their characteristics are combined to yield the composite system dynamics. However, the actual levels of skills required in solving real design and fault diagnosis problems is usually only implicitly determined by the problems provided in standard text books etc. For instructional software development, the more clearly the capabilities which the learners are expected to construct can be specified, the easier the whole development process becomes. However the learners' own personal learning goals (reproduction, or deep understanding, or just course-marks[7,8]) must be explicitly taken into account.We have mainly been concerned to provide aids which will encourage surface learners to think more deeply about the components (e.g. converters and motors), circuits (controllers) and systems which they will design and specify.

II - NEEDED ***CONTROLS***

In the case of classroom presentation and demonstration software the controls are instituted by the instructors and demonstrators usually in an ad-hoc fashion. However, when packages such as OATS [9] and our CD-ROM are produced, arrangements need to be made to guide the learner(s), and to provide scaffolding, to provide for self-tests and to record and exhibit progress clearly so that the learner(s) can make wise choices of how much time and effort need to be spent to achieve *their* goals. In OATS we did this using the QUEST+(tm) authoring language as a scaffolding shell, but that inhibited the students computational and graphing capabilities. Currently we are using MathCad(tm) worksheets which are very flexible. We are working on integration of the two approaches in POWERGUIDE to achieve better meta-cognitive control support for the learners.

III - UNDERSTANDING THE LEARNERS' ***PSYCHOSTRUCTURES***

As Biggs [7] and Entwistle [8] have established, higher and further education students (in a given course at least) may be fairly well categorized as functioning in one of three modes: 1) as Personal meaning (deep knowledge) seekers, 2) as reproductive (surface) learners, or 3) as grades oriented game-players (intent on getting a good grade by any means). Different instructional support materials and control strategies are required for each.

IV - MANAGING ***SOCIOSTRUCTURES***

In our initial work, students work either as partners, or alone, either in laboratories with some instructor support, or at home with Internet communications.

V - ***MATHEMATA*** *(ACKS) Attitudes, Concepts, Knowledge, Skills TO BE LEARNED*

The topics chosen are important topics in the standard curricula which are also ones posing appreciable conceptual difficulty for a fair number of students.

The essential ATTITUDES of successful engineers and technologists include:

i) *curiosity*, about possible alternative designs sand understandings, ii) *Openness*, an attitude of openness to correction, and of openness to re-framings and re-naming, in the light of new tools, new facts, arguments, and new needs is crucial, iii) *Commitment* of high quality attention-time, a few hours a day will do.

The KNOWLEDGE to be acquired depends on the state of knowledge in the field, and the entry knowledge profile of the learner. More concretely with respect to the Electrical curricula, the topics are about the components (e.g. Passive R-L loads, converters, and motors, controllers) embedded in industrial systems, which they will study, research and design. SKILLS: The skills to be acquired similarly depend on the state of the art, and entry level skills of the learners. However, always, *meta-cognitive skills* for managing personal learning conversations with ones-selves and others are of great importance [1].

*VI - **ILLUSTRATA** MODELS AND SIMULATIONS*

The POWERGUIDE models are Systemic problem worksheets, computational simulations of components, circuits, and algorithmic computer animation displays. The tutorial simulation combines two modes of discourse: didactic and experiential. Laurillard [10] describes the two types of feedback particular to these modes: extrinsic and intrinsic feedback. The tutorial aspect of instruction involves extrinsic feedback, which consists of comments on the learner's action (e.g., "That is correct" or "Please choose a different option").

The simulations, however, offer intrinsic feedback. *Intrinsic feedback* is any consequence of an action taken by the learner which (s)he uses to modify (her)his learning activity. in our prototype project OATS, if the learner inputs a certain value for the feedback resistor into the mathematical model of an operational amplifier circuit, then the resultant value of the output voltage provides intrinsic feedback, to let the student know if (s)he is on the right track.

It is still unusual to find both these modes, didactic and experiential, combined in a single instructional program. They tend to be used as distinct types (e.g., expository versus discovery approaches to instruction, in the Reigeluth & Schwartz [11] terminology).

*VII - **MEDIA learning environment***

The media which have been chosen for the POWERGUIDE Electrotechnology package are computer software with animated graphics, occasionally combined with face-to-face, or computer-communications mediated conversation. Whatever media are chosen the first pre-requisite is good signal-to-noise ratios. In particular, the core content must not be obscured by the "artistic" efforts of the multimedia designers as is often the case when advanced multimedia authoring tools are used.

Since the co-evolution of tools is necessary to the evolution of knowledge and skills, the most important classes of application software are specifically tailored yet flexible modeling and simulation tools. We have worked with a number of applications such as: MathCad, P-Spice, Electronics Workbench, Quest+, and found that in such commercial software one either has very great flexibility (MathCad), or powerful multimedia guidance, testing and record-keeping capabilities (Quest+, Authorware Professional, Web-CT) but not both classes of function at once. {Student produced software in C++ or

JAVA has proven so far to be too time consuming to develop and/or too buggy.} At present we continue to use MathCad and Quest+.

The computer-based software provides the students with an interactive constructivist learning environment. The students construct their own understandings by exploring the effects of systematically changing parameters and configurations over a wide range of situations. This is possible because the software is designed to remove the drudgery of complex computations and to display the results in a clear and attractive graphical form.

VIII - ***CONTEXT*** **- physical environment**

The work is being carried out in Vanier College(CEGEP) which offers three year programmes in Electrotechnology. and in the Electrical and Computer Engineering department of Concordia University.

The physical environments for student learning, and formative evaluation, currently in use in our project are conventional EE laboratories with networked PCs.

VI. Zooming in on POWERGUIDE

The approach is based on an electronic workbook illustrating the basic concepts by means of practical examples taken from typical industrial plants.

The principal software package selected as the backbone is the mathematical spreadsheet Mathcad, because of its capabilities of handling technical mathematical problems as well as its advanced features such as hyper link and graphical abilities.

The structure is dictated by the requirements of curriculum and the component described above as *Dimension I, Managing Goals* and *Dimension II, Controls*. The user is presented with the structure of a typical industrial electrical power system, Fig. 2.

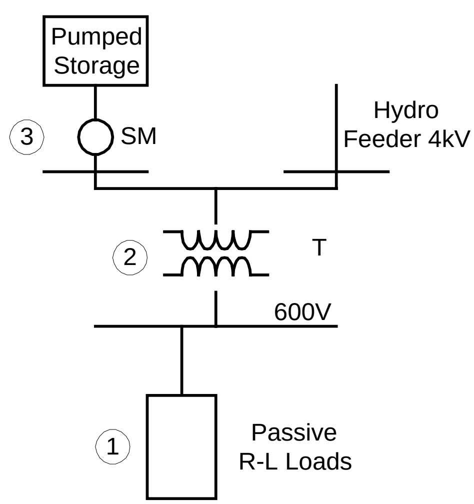

Fig. 2. Sample industrial system; the EE context of the instructional package. (Numbers refer to topics covered in the instructional material: 1: AC loads, 2: Transformers, 3: Synchronous machines).

The components of this system are chosen to cover i) most of the subjects in the curriculum, ii) the more relevant and difficult elements of the theory, iii) useful industrial concepts and systems. Within each topic, a progression from the simplest components to the more sophisticated is offered to the user. The basic classes of components treated are indicated in Fig. 3.

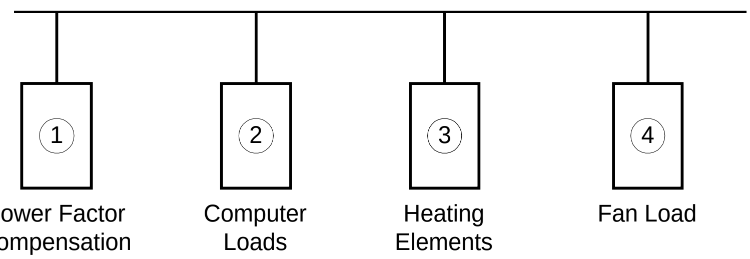

Fig. 3. Built-in typical industrial loads and compensation equipment.

Instructional Simulation techniques

The underlying electrical principles are exhibited by means of simulations of typical devices, such as three-phase loads, transformers, motors, and electronic loads.

Each topic is associated with the basic theory and equations required to compute the characteristics and performance of the components and at a higher level, of the system or overall plant. From the instructional perspective, the design is based on ideas dictated by found in *Dimension III, Understanding the learners' psychostructures*.

Different instructional support materials and control strategies are exploited. The equations are used to solve a sample problem. The parameters of this sample problem can be modified as desired. Software design is based on ideas found in *Dimension VI, Illustrata and Simulations*.

The electronic book also provides the students with the theoretical aspects of each device under study using hyperlinks.

Simulation software structure and development

The following features are incorporated into the interactive software:

(a) The theoretical core of the software is an explanatory text presenting the conventional theory. However, the learning process is enhanced by means of an extensive use of hypertext links to help students navigate through the theory, simplify cross-referencing and keeping track of basic concepts, definitions and equations. Where appropriate, animated diagrams are used (*Dimension I, Goals*)

(b) A computing engine is incorporated into the software package to enable students to pose problems for themselves and to solve set problems, with hints and helps. This engine allows the student to make conjectures as to how things will behave based on her/his understanding of the electrical & electromechanical mechanisms involved and apply trial and error techniques and experiential learning concepts. Self-testing of understanding then becomes central to learning (*Dimension II, Controls*). The students singly or in groups can modify the data of the problem and therefore get a better understanding of the interacting effects of changing the variables and parameters of the system under widely varying conditions and beyond what is possible in conventional hardware laboratories (*Dimension III, Psychostructures*).

(c) The computing engine is of a mathematical spreadsheet type, and helps remove the difficulties in carrying out complex computations (*Dimension V, Mathemata*).

(d) The approach and solutions are extended to examples of "real life" engineering problems drawn engineering experiences in industry. The approach is similar to the "case study" approach, which has proven successful mostly in other disciplines (marketing and finance) and recently in engineering design, mainly mechanical (*Dimension VI, Illustrata*).

(e) The application is interactive, allowing many different case studies to be carried out in a reasonably short time, compared to lengthy process involved in manual or even calculator-based solutions. Different contexts and settings can be used, representing various industrial system configurations and modes of operation

Extension of the learning experience

The software allows the instructor to assign thought-provoking activities, including small design projects. Such projects offer the opportunity for guided learning conversations among the project participants (either face-to-face or via Web-CT).

The software package selected as the backbone is the mathematical spreadsheet Mathcad (*Dimension VII, Media*). This choice is based on the requirements discussed above. The package has capabilities of handling technical mathematical problems, and has advanced features such as hyper link and graphical abilities. An executable version can be created, removing the need to run a copy of the software package.

The structure of the instructional aspects of the proposed tool is dictated by the requirements of curriculum and the component described above as *Dimension I, Managing Goals*. The user is presented with the structure of a typical industrial electrical power system, Fig. 2. The components of this system are chosen to cover i) most of the subjects in the curriculum, ii) the more relevant and difficult elements of the theory, iii) useful industrial concepts and systems. Within each topic, a progression from the simplest components to the more sophisticated is offered to the user, Fig. 3.

The approach is based on an electronic workbook illustrating the basic concepts by means of practical examples taken from typical industrial plants.

The project was carried out in the following steps:

(a) Rewriting the theory taking into account the fact that various facets of the theory can be readily illustrated dynamically. An authoring system, Quest+, will be used wherever possible. Various 'state of the art' EM computing packages will also be considered.

(b) Creating hyperlinks to cross-reference definitions, equations and theoretical concepts.

(c) Developing examples, of two basic types, conceptual on the one hand and related to real engineering systems, on the other.

(d) Developing the interactive aspects, the cognitive construction transactions, and both the graphical and computational aspects, using the authoring system.

Model Problems

Fairly simple yet well contextualised problems with scaffolding for solution are given as models to start with. For example, the problem of finding currents in a passive three phase Y-connected load is shown in Fig. 4. Results are illustrated in Fig. 5. A similar study is available for delta connected loads. This allows the student to analyze different situations, calculate circuit parameters and give a plausible quantitative cost benefit analysis and arguments for whether "WYE" or "DELTA" connection modes should be used for a specific application, given a technology and associated implementation costs.

A balanced three-phase load is connected to a balanced three-phase source as shown Fig.2.5. Both have DELTA connections. The load will consist of a heating element. Industrial heating elements are generally defined in terms of their power rating and their operating voltage. Imagine that the impedance Z in Fig.2.5 is replaced with a specific heating element. The objec of this particular exercise is to obtain expressions for all the line and phase quantities.

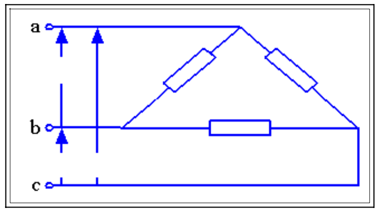

Fig.2.5

Let's first calculate the line-to-line and the phase voltages. The source voltages otherwise known as the line or line-to-line voltages are defined as:

$i := \sqrt{-1} \qquad k\Omega \qquad V := 440$

$theta_0 := 0 \quad theta_1 := \frac{-2\cdot\pi}{3} \quad theta_2 := 2\cdot\frac{\pi}{3}$

$V_{ab} := V\cdot e^{(i\cdot theta_0)} \quad V_{bc} := V\cdot e^{(i\cdot theta_1)} \quad V_{ca} := V\cdot e^{(i\cdot theta_2)}$

$|V_{ab}| = 440 \qquad arg(V_{ab}) = 0$

$|V_{bc}| = 440 \qquad arg(V_{bc}) = -2.094$

$|V_{ca}| = 440 \qquad arg(V_{ca}) = 2.094$

$V_{ab} = 440 \qquad V_{bc} = -220 - 381.051i \qquad V_{ca} = -220 + 381.051i$

The Phase voltages and the line voltages are equal

$V_a := V_{ab} \qquad V_b := V_{bc} \qquad V_c := V_{ca}$

The impedance values can be defined as the value of the resistance of the heating element. These values may be different depeding on the relationship between the heating elements power capability and its operating voltage.

$HeatingWatts := 10000 \qquad HeatingVolts := 240$

$HeatingResistance := \frac{(HeatingVolts)^2}{HeatingWatts}$

$ImpedancePerPhase := HeatingResistance$

$ImpedancePerPhase = 5.76$

The line current and the phase currents are identical and therefore they can be found as:

$I_{ab} := \frac{V_a}{ImpedancePerPhase} \qquad I_{ab} = 76.389$

$I_{bc} := \frac{V_b}{ImpedancePerPhase} \qquad I_{bc} = -38.194 - 66.155i$

$I_{ca} := \frac{V_c}{ImpedancePerPhase} \qquad I_{ca} = -38.194 + 66.155i$

Fig. 4. Example problem and theoretical background.

The phase currents are related to the line currents by a factor of root three.
Therefore the phase currents are:

$$I_a := I_{ab} \cdot \sqrt{3} \qquad I_b := I_{bc} \cdot \sqrt{3} \qquad I_c := I_{ca} \cdot \sqrt{3}$$

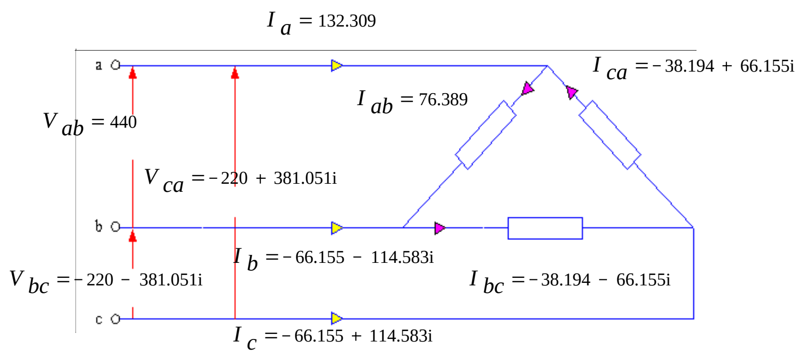

Fig. 5. Problem model and sample results.

Formative evaluations

Formative evaluations are currently being conducted with college and university students and some results will be presented.

The following improvements in teaching, leading to a change in teaching perspective, have been obtained in the classroom, and can be extended to material developed for distance learning using Web-based material:

(a) Illustration of the theory. Concepts taught through equations are synergistically linked to and solved by simulation.

(b) Learning by example. The simulation environment is interactive. Solving problems with different inputs is straightforward. Models are data driven and incorporate industrial settings.

(c) Minimizing abstract content. The tedious mathematics and manipulation of equations can be reduced to a minimum, which usually does not lead to additional insight.

(d) "Scaffolding" for the use of simulations and for problem solving, which is faded away as the student progresses, will be provided.

Validating of the learning process will be made possible by analyzing user-trail files generated by the interactive textbook with each student (who volunteers to provide such data) and by determining the enhancement in the student knowledge obtained, using written questionnaires or other appropriate means.

It is observed that the chosen approach has a number of instructional advantages such as: i) the student does not have to deal with complex mathematical calculations to get the desired answer, ii) the student can therefore repeat the calculations a number of times with different parameters and get a feel for the behavior of the component, iii) the student can easily study the impact of parameter changes on the overall system.

Further results will be presented at the conference.

IV. Conclusions and recommendations

Only tentative conclusions are possible at this juncture.

The POWERGUIDE tutorial simulations therefore combine two modes of learning support: didactic and experiential in ways which enable student co-construction of knowledge and skills. Consequently this work is a contribution to educational technology professional knowledge and instructional design and development methodology, as well as to electrical engineering education.

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Bigraphies

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