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Instructional design strategies for interactive Web-based tutorials and laboratory procedures in engineering education

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ABSTRACT: Designing and developing effective, intelligent Web-based tutorials is a difficult and time-consuming task that requires proper planning and patience. On the other hand, determining the effectiveness of a developed program is very much pertinent in the computer-assisted learning technology. Numerous research works on Web-based educational systems have shown that there are very few laboratory-based, effective and intelligent tutorial systems, which have been developed thus far within the engineering domain. Comprehensive research of the overall effectiveness of any developed Web-based education system for its learning performance and usability is a major and essential component of teaching methodology. This paper addresses a few important issues related to the design and development of Web-based intelligent and interactive tutorials and laboratory procedures in an engineering domain, with examples from basic electrical engineering. The paper also advocates appropriate instructional design strategies to be implemented in the development of online laboratory procedures in the engineering domain, which can also be generalised and applied to other domains.

INTRODUCTION

With the introduction of computers in the teaching/learning process and the emergence of the Internet, a large number of Web-based educational applications have been developed. However, very few of them are really and truly interactive for teaching/learning purposes. Moreover, they are mostly built with one objective: to be used for a specific course in a specific academic institution. The development of any Web-based tutorial system is a difficult task and it involves accurate and proper planning of various processes from coding to evaluations. Recent hardware and software developments, rapid growth and advancements in Internet technologies and the evolution of new learning theories have all influenced the challenges in Web-supported instructional technology in education.

COMPUTER-ASSISTED INSTRUCTION

Computer-assisted instruction plays a very important role in the modern education process and extensive research shows increasing evidence of the use of computers in the teaching-learning process. Some evidence has shown that computer-assisted instruction, which focuses on higher-order learning in technical education, has been more effective than traditional instruction [1]. However, comprehensive research is required to determine the best methodology to be applied to the design and development of computer-assisted instruction, as well as the efficiency of the teaching/learning processes based on this particular method of instruction.

RESEARCH ON WEB-BASED EDUCATION

Recent research into the application of computers and computer technology to engineering education has indicated that many academics consider the use of computers in teaching practice as a worthwhile alternative to traditional teaching methods, particularly in such a demanding discipline as electrical and electronics engineering. However, educational research on the effectiveness of computer-based education in general, and engineering education in particular, has been somewhat fragmented and, so far, limited in scope.

The evolution and advancements in hardware and software technology have resulted in the development of more sophisticated authoring tools for computer-based learning. Numerous literature searches have shown evidence that such development began in the early 1960s, with the simple graphical and animated programs like *PLATO* and *TUTOR*. In later stages, due to the growth in multimedia and hypermedia technology, as well as the use of artificial intelligence and expert systems in learning, several new packages were developed as authoring software, including *ToolBook*, *Spice*, *PSpice*, *Simulink*, *Electronics WorkBench*, etc.

Since early 1990s, when the World Wide Web (WWW) was introduced, there have been major changes in the instructional delivery method; this has proven to be the most important medium as well as a useful tool for education. However, research related to Web-based learning and teaching has been narrowed to explore important pedagogical issues. Most of this research in the development of online education has been carried out to find the differences between traditional learning and Web-based learning [2]. Research efforts have also been concentrated on the evaluation and effectiveness analysis of Web-based learning portfolio in terms of its functions in the system [3]. But, this particular study does not include an evaluation regarding the efficiency of the system utilised. Recent advances in online research on this mode of learning formulate the desperate need for more qualitative basic research on Web-based learning, as well as a rigorous assessment of developed Web-based courses [4].

LABORATORY PROCEDURES

One of the essential instructional design strategies in learning theory is to facilitate and increase a learner's efforts in order to make the learning process more effective and useful. Engineering students need to be prepared for the increasing use of advanced and appropriate technology in their future workplaces. Laboratory procedures are essential learning tools in engineering and technology education that can be used to enhance the experimental instructions in engineering courses. The Web-based self-study procedures in engineering courses are most pertinent to motivate and encourage active learning with heuristics and an independent approach. Exposing the use of computers in laboratory instructions to students in science, engineering and technology courses is essential to make them familiar with the technology and its practical applications.

SURVEY OF LABORATORY PROCEDURES

It has been found that many computer-assisted laboratory online courses are developed as computer simulations, using the most popular and commercially available authoring tools, such as *LabView*, *ToolBook*, *Authorware*, *Electronics Workbench*, *Spice*, etc. However, purchasing such readymade software is not worthwhile, as they might not suit the targeted learning goals. A survey on the relevant literature of design and development of Computer-Assisted Instructions in the engineering and technology domain has led to the discovery of a few developments, as listed below:

- The introductory sophomore linear circuits course at the University of Southern California, USA, was taught via the Web using *Mallard* software; the students' response to this format was extremely positive [5].
- A project based on Computer-Assisted Instructions (CAI) via the Internet for first year university students, with a problem-solving approach, has been carried out by de Mul et al at the University of Twente, the Netherlands [6].
- Quantitative research on students' achievements, in order to determine the effectiveness of an online laboratory course in electronics, was carried out by Thomas Hall at Northwestern State University of Louisiana, USA [7]. In this project, the computer simulations were compared with traditional laboratory procedures used to perform experiments. As a conclusion, the result outcomes explored the need for more qualitative research.
- An experimental set-up using a distance education remote laboratory was tested for learning performance via the Internet at Florida Atlantic University, USA, by Alhalabi et al [8].
- Berntzen et al of Norway described advanced solutions in order to perform laboratory experiments over the Internet, including the commercial software package *LabView* [9].

DESIGN AND DEVELOPMENT OF CAI

Although the design and development process of CAI involves a team effort from various professionals and experts, such as a course designer or evaluator, there are packages also being developed individually by a single person. Soulier explains that there are three main instructional design stages of computer-based instructions: planning, development and evaluation [10]. All three stages are important. However, the development stage is one of the most crucial stages and involves the development of suitable authoring tools. The design and development of appropriate authoring tools have a direct impact on the performance of the computer-assisted learning technology. Moreover, while designing and developing best suitable instructional strategies for the desired learning objectives, one has to consider important pedagogical and technological issues associated with this process.

DEVELOPMENTAL ISSUES

The increased use of the Internet in learning and the advancements of new authoring tools in computer-assisted learning have created challenges and opportunities for teachers and developers, especially as far as Web-based pedagogy is concerned. Most researchers and educators have found the Web as a potential resource to support learning pedagogy. Fetherston proposed that debate surrounding the use of the Web in university teaching should centre on learning and not technical issues [11]. Since computers are being used as pedagogical tools in education, the hypermedia and multimedia technologies that support and facilitate Web-based instruction should make the process more effective. Educational research proves that Web-based designed courses, when founded upon proper pedagogy, always help in motivating learners and encouraging learning behaviours for specific learning goals. It is also important to formulate how available technology can be used to facilitate desired learning objectives within the psychological and pedagogical constraints. Table 1 outlines the important pedagogical and technological points to be considered in the selection and development of a suitable instructional strategy.

Table 1: Important instructional considerations.

Pedagogical Issues	Technological Issues
Learning goals/objectives	System availability
Learning material	Mode of delivery
Target (end) users	H/W resources
Cognitive mapping	Internet bandwidth
Interactivity	Programming tools

SELECTION OF INSTRUCTIONAL STRATEGIES

Once the learning objectives are fixed for the proposed Web-based system, the developer has to select an appropriate instructional strategy to be implemented. Instructional strategies are of utmost importance in the quality of Web-based education. There are various instructional strategies that can be implemented in Web-based education such as: tutorials, drill and practice, laboratory procedures, simulations, etc.

In the case of an instructional strategy applied to the engineering domain, it is suggested to apply an effective, experimental-oriented and heuristically approached strategy. Hannafin points out that those individual learners who have limited prior knowledge may lack the initial understanding of the concept, which is required in order to quickly assimilate new information. As a result, learners tend to be more dependent on the instructional structures provided by the designer in order to acquire a new concept or knowledge [12].

INTELLIGENT TUTORING

Research carried out by Yaakub shows evidence that for higher order learning in technical education, Intelligent Computer-Assisted Instruction (ICAI) was significantly more effective than that of non-intelligent computer-assisted instruction [1].

Most of the traditionally developed ITSs are static and standalone in nature, and it is very difficult to deploy advancements and changes in the courseware if they are designed based on authoring systems that do not include elements of artificial intelligence. The appropriate way to minimise the disadvantages of traditional intelligent tutoring systems is to utilise the World Wide Web (WWW) or the Internet.

COGNITION AND INTERACTIVITY

According to Riva, in case of Web-based learning tools, it is essential to use the so-called concept of *interbrainframe* [13]. Furthermore, he states that hypermedia can be considered as one such important tool, which is a sort of computer-stored information that is retrieved and related via links. The study also shows that learners can acquire cognitive strategies when learning is independent, intellectual and efficient [14].

The instructional strategy with interactivity contains text, graphics and audio-video objects that are incorporated within the learning material. The extensive literature review reveals a great deal of work on the effects of multimedia on learning; however, most of this work is confusing rather than helpful to the instructional designers in education, as commented by Hannafin [12]. It is, therefore, desirable to utilise available technology, such as multimedia, in order to promote better and effective learning outcomes in the learning process.

CHARACTERISTICS OF THE MODEL

The following characteristics seem to be essential in order to design ideal software with appropriate instructional strategies for Web-based education in the engineering domain:

- The designed system must be user friendly, easy to use and task oriented.
- The instructional design strategy must be able to provide the most appropriate encouragement for self-motivation.
- The design strategy should incorporate simple Web delivery methods with minimal standards of the desired content.
- It should provide realistic solutions to the problems by the principle of *complex to simple converter*.
- The design must be learner centred and not developer centred, which should provide opportunities for learners to test theories and explore their own learning.
- The design strategy should develop active learning, facilitate essential thought processes and result in a positive impact on the learning outcomes.
- The design must make use of the technology and include educational facilities for self-assessment by learners throughout the learning process.

SEQUENCING AND PROTOTYPING

The design framework of the Web-based system in the engineering domain must contain intelligent and interactive components that will fulfil the desired learning needs. It is essential to consider the available methodologies, as well as individual learning styles and learning abilities, while developing any instructional strategy. The Web-based instructional strategies in engineering education must include at least four essential components as described in the instructional design framework depicted in Figure 1.

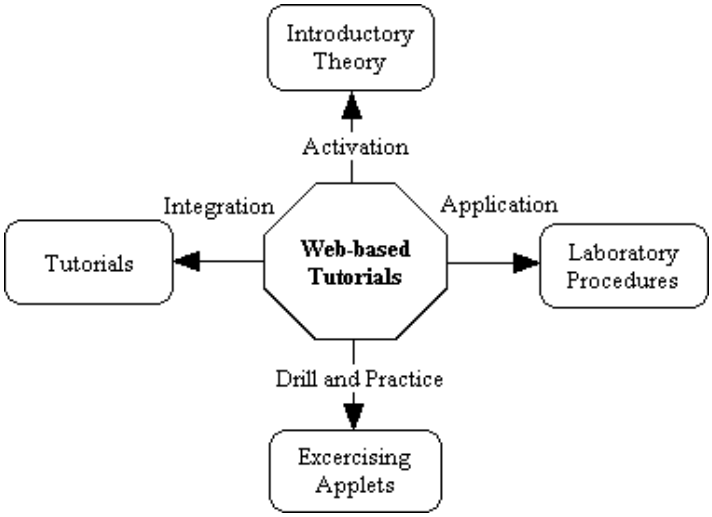

Figure 1: Instructional design framework.

When considering all the important issues related to the design and development of Web-based instructions for online self-study procedures in the engineering domain, in an attempt to design a most effective model, it is logical to accept and apply different instructional principles [14][15]. Further, the proposed model also incorporates important, so-called *first principles* of instructions, as identified by Merril, such as activation, integration and demonstration [15]. Figure 2 presents a screenshot of one of the chapters of the designed software suitable for the study of circuit theory in basic electrical engineering. Important pedagogical and technological elements and assumptions of this software include:

- Learning objectives: to expert students in circuit theory of basic electrical engineering.
- Course material: *Basic Electrical Engineering: Laboratory and Tutorial Procedures* and also *Lecture Notes* [16].
- Target users: first year electrical engineering students from any university around the globe.
- Mode of delivery: via the Internet.
- Authoring Tools: independently developed authoring tool with the aid of sophisticated and flexible programming tools.
- Programming languages used: HTML, DHTML, Java, ASP, JSP, Java script, etc.

In the case of undergraduate courses in electrical engineering, it is essential to achieve a certain level of comprehension of the physical phenomena, basic concepts and principles in circuit theory. Students should also understand how to apply these basic concepts in practice, which are useful in other electrical engineering courses, later in the degree programme. It should be noted that it is difficult to teach circuit theory in the classroom; however, it is believed that students can excel better in circuit theory when using online multimedia technology at their own time and pace.

In developing instructional strategies, authoring languages should be selected so as to make the programmer's task easier and more flexible. Java is a fully object-oriented programming language and one of the fastest growing programming technologies of all the time. It is regarded as the most important language for Web and Internet applications. Java, being a specialised programming language that contains multi-level function performing tasks has, therefore, been used as the authoring language to design and develop this software.

CONCLUSIONS

Developing intelligent and interactive Web-based tutorials and laboratory procedures is a difficult and time-consuming task. The core part of any design and development of Web-based educational software is the adoption of proper instructional design strategies. The effective instructional design strategy in the engineering domain should be based on important pedagogical and technological considerations. The pedagogical strategy must include at least four essential components, such as activation, drill and practice, application and integration, whereas the technological strategy must include and facilitate interactive and intelligent activities within the designed Web-based software.

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Figure 2: A screenshot of one of the chapters of the designed software.