DIGITAL SYSTEMS AND ELECTRONICS CURRICULA PROPOSAL AND TOOL INTEGRATION

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Abstract — *To transmit the teaching of digital electronics today, the considerations outlined below must be kept in mind. Digital electronics is evolving quickly and its techniques and tools have revolutionized the manner of analyzing, simulating, synthesizing and verifying digital systems. Microelectronic development is more and more depending on the technology and on design methodology. Standard hardware description languages (Verilog and VHDL) together with simulation and synthesis tools are some of the drivers behind microelectronic development.*

The "constructivist" model in the teaching-learning process proposes: significant learning as opposed to memorizing; structuring and sequencing of content; learning through guided discovery and a spiral or recurring procedure.

These circumstances together with pedagogical concern and the knowledge and experience that the authors have acquired as digital electronics teaching Professors have resulted in the formulation of a curricular proposal to transmit this updated teaching method. Using this teaching model as a base, the aim of this proposal is to have the student studying digital electronics acquire the theory and practices (know-how) from the beginning by using current design methodologies and CAD and EDA tools that the students will use in their professional future. Another objective of this method is to provide students with multimedia applications as a learning resource.

Index Terms ¾ computer aided electronic engineering, simulation and tools, digital electronics analysis and design.

INTRODUCTION

Digital electronics and its design methodologies

Digital electronics is evolving rapidly and its techniques and tools have revolutionized the manner of analyzing, simulating and synthesizing digital systems. Microelectronic development is more and more dependent on technology and on design methodology, as once the technology has been developed, design methods and tools must be created that allow complex systems to be implemented with minimum time and development costs to assure their competitiveness.

Hardware description languages (Verilog and VHDL) as well as simulation and synthesis tools comprise the top-down design methodologies and are the driving forces behind microelectronic development. The objective is to focus efforts on functional level concepts, allowing for the evaluation of alternative solutions before embarking on the detailed design and physical implementation (synthesis). This gives rise to so-called high-level design.

These languages also facilitate the reuse of code and engineering and they have the advantage of using a single language throughout the entire design process, thus simplifying management and reducing the number of tools and formats used.

Today, PCs make it possible for anyone to have access to these design tools and methodologies.

University Teaching and Learning

The role of the university student in the teaching-learning process must be active, with the student taking the initiative to learn. Thus, student education must be considered from a cognitive focus and through its associated teaching theory: constructivism.

In cognitivsm, the student is an active information processor and the teacher provides learning, which is perceived as a stable change in what the student knows, does and thinks. Furthermore, instruction is a personal knowledge building process, not a simple transference of knowledge.

The most important and influential authors on Cognitivsm, (Ausubel and Bruner), have contributed different focuses to model the teaching-learning process. On the one hand, Ausubel [4] contributed the concept of significant learning to constructivism as opposed to memorized learning. He also demonstrated the importance of structuring and sequencing content "tell them what your going to tell them, tell them what you are telling them and then tell them what you've told them". Furthermore, the main contribution from Bruner [6] was learning through

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guided discovery and problem solving, which can be carried out through simulation activities and games. Another of Bruner's contributions was the spiral or recurring curriculum, which sees the same content at different levels of complexity in successive situations.

In the spiral concept of learning, the teacher must provide the student with the acquisition of a basic nucleus of knowledge and the tools that allow the student to continue learning based on that nucleus.

Using the constructivist models of the teaching-learning process, the simulation and the formal hardware description languages for systems applied to the teaching of digital electronics play three very important roles:

- Favor significant learning of the material.
- Good tools for learning through guided discovery.
- Essential tools for spiral learning, as based on a knowledge nucleus, they allow systems with different levels of complexity and abstraction to be defined.

TECHNOLOGY EVOLUTION

The evolution of current technologies reinforce this need:

- CMOS technology continues to be the most widely used, with 75% of the market share and growing. Bipolar/ECL technologies are holding at 15%. BICMOS technologies have risen to 5%. NMOS, TTL are growing, together with new technologies of the AsGa type, which comprise the remaining 5 %.
- New encapsulating technologies in multichip modules (Multichip Modules, MCM) allow dice shaped chips to be mounted directly on different surfaces (ceramic, laminate or silicon), where connections between different chips had previously been made. This allows performance to be increased: speed, consumption, etc. and decreases the size of electronic systems. These are the natural evolution of hybrid circuits.
- Other technologies related to microsystems allow, together with microelectronics, the integration of sensors and actuators in miniaturization processes.
- Electronic circuits are increasingly more complex, particularly digital devices. Analog (A) and mixed designs (A/D) with BICMOS technologies are increasing, the latter including power devices (A/D/P).
- Full and semi-custom ASICS are no longer as important given the performance and complexity that programmable devices are able to offer, so that only in large production runs or very specific requirements (confidentiality, area, speed, etc.) are custom-ASIC necessary.
- The study of sub-micronic technologies is advancing (CMOS with a channel length under 0.3 μm). These are able to integrate several million devices and connections on very few mm^2.
- Once again microelectronic development is dependent on design more than on technology. It is currently becoming possible to implement complete systems in a single silicon chip (SOC, system on chip; SOS, systems on silicon) and the problem is again a lack of methodology and tools to undertake such complex designs. Designs are based on macro functional blocks (CPU, DSP, μC, etc.) developed in software (synthesizable VDHL code) or optimized at a hardware level (layout or specific topography) where the current development level is not ideal, but a great amount of effort is being invested in achieving it.

CURRICULAR PROPOSAL

The considerations noted in the introduction and the pedagogical concerns, knowledge and experiences that the authors have acquired as teachers in digital electronics have led to the formulation of a curricular proposal for an updated teaching of digital electronics. This curriculum is justified below [3].

One: Knowledge and use of a hardware description language

Hardware description languages (HDL) such as Verilog and VHDL allow for the use of top-down design methodologies. They also have the advantage of using a single language throughout the entire design process (modeling, simulation, synthesis and verification), simplifying management and reducing the number of tools and formats used.

The knowledge and use of a standard hardware description language as well as its simulation and synthesis tools allow the student or party interested in studying digital electronics to:

- Describe a circuit **independently from technology.** This is very useful from an educational viewpoint when one desires to highlight the functionality of a system when initially studying it, avoiding other less relevant aspects that can complicate or hide the main objective at this point.
- Describe a circuit **independently from the design tools**. To that end, a standard HDL language must be used, so that any tool meeting the standard provides portability.
- **Choose one or several levels of abstraction** when defining a digital system. This allows each block to be defined in the most suitable manner (functional, register transfer, gates).
  The level of abstraction can also be chosen based on what is to be performed: simulation or synthesis. In the education environment this provides flexibility as it allows for the study of an element or digital system from several aspects and levels of abstraction, including top-down design analysis.
- **A hardware description oriented to simulation** is very advantageous in education, as it allows for the analysis of digital systems that are too costly, dangerous, large, etc., to be implemented by universities or other educational institutions.

- **A hardware description oriented to synthesis** is one of the best current paths for the physical implementation of digital systems via programmable logic devices (PLDs). This allows the advantages provided by integration to be made use of (size, consumption, reliability and price) by replacing traditional LSS and MSI circuit connections with PLDs in laboratories.

Two: Use of computer simulation

Resolving problems and system designs by computer simulation is comprised of reflecting, imitating a physical system in a virtual or real manner, by the use of a model that allows conclusions on its performance to be determined. In computer simulation a system **model** must be created from its description. The creation of this model forces the student to determine and precisely document the operation of the system, bringing forward possible problems or indeterminations not considered in the initial specifications.

Some of the circumstances where simulation is especially useful are:

- The **real physical system does not exist,** is dangerous, too costly, construction consumes large amounts of time or a real model or prototype can not be implemented, and it is thus better to do a virtual prototype or model programmed on a computer.
- **The real physical system exists,** but its observation and experimentation is dangerous, inaccessible, destructive or costly.
- A model is needed that allows performance to be **predicted over long periods of time** in a compacted fashion.
- The mathematical or formal model of the physical system **does not have an analytical solution**, thus its analysis or verification are not possible.

Simulation is a necessary tool for design professionals and researchers [9]. It is also a highly helpful tool for students, as it allows them to experiment with the theoretical knowledge they acquire and study it in more depth.

The importance to be given to this tool in university education is a result of all of the aforementioned. Additionally, advances in personal computers, together with their drop in price, have made it possible to use several simulation programs that were previously exclusive to companies devoted to tasks in the fields of engineering, design, etc. and which are now accessible to most students.

In the teaching-learning process, simulation tools have a clear application in the "learning through guided discovery" focus. To that end, exercises and practical cases need to be developed that lead the student to a previous theoretical analysis process followed by a continuous discovery of the "true" operation of the circuit and its usefulness and limitations.

In education, computer simulation allows the student to:

- Verify the results of circuits analyzed theoretically and understand their usefulness.
- Analyze the influence of certain circuit parameters on overall operation.
- Based on the models, evaluate the limitation of circuits which approach the real performance rather than the ideal model.
- Research changes in circuit topology to improve performance.

This allows the student to expand and modify knowledge, previously acquired by theoretical analysis, through simulation. In this manner learning will be long-lasting, as students will find a sense of the knowledge acquired and perceive close contact with reality at all times.

Simulation tools are ideal for students to continue learning by themselves, as they allow conclusions to be extracted through the simple variation of a parameter and bring students closer to real circuit performance.

Electronic simulation tools are widely used in industry and research centers. Thus, developing the students' habit of working with these tools not only achieves an improvement in the learning process, but also prepares them for their incorporation into the job market.

Simulation with different applications

As the objective desired is to develop a work methodology and critical mind-set in students when evaluating the results of electronic circuit simulations, regardless of the application used, it is in the interest of students that the guided exercises developed use different applications.

This will allow results obtained from the different applications to be compared to reach conclusions on the models and algorithms used for each application [7].

Conclusions the student must reach

The conclusions to be reached by the student are:

- the results of the simulation are precisely those previously calculated by the model used, with a greater or lesser approximation to the real model.
- the possible discrepancies with the solution obtained can be explained depending on the models used to approximate the real characteristics.
- from these results, the student is able to observe the influence of a variation in a certain circuit parameter on the operation of the whole circuit.
- the student is able to slightly modify the topology of the circuit to improve certain characteristics of the circuit.
- One important fact is to interpret the results of the simulation, regardless of the application used to achieve those results, with the student being aware that the results can change from one application to another due to the different models and algorithms used.

Three: Study of the design process flow of digital systems

It is important for the student to receive complementary education on the process of definition, management and control of the design flow of digital systems.

These allows the student to use concurrent engineering, top-down design methodologies, code re-use, etc., thereby achieving greater knowledge of the professional environment in the design of digital systems.

Four: Availability of complementary material to the student: public domain CAD and EDA, with their manuals and tutorials

Provide the student with public domain CAD (*Computer Aided Design*) and EDA (*Electronic Design Automation*) tools, educational and/or evaluation versions, with their manuals and tutorials.

The aim is to assure that students acquire theoretical knowledge and know-how from the beginning through current design methodologies and the use of CAD and EDA tools that they will use during their career, such as: systems modeling described in VHDL, computer assisted simulation, synthesis and verification of a system in a specific technology.

Five: Guided student learning through Exercises and Practical Cases

The development of practical cases and exercises to learn Electronic Engineering through simulation must be performed considering the guided discovery learning model and the spiral model of the teaching-learning process.

Guided student learning through resolved and follow-up exercises

It is effective to provide **resolved exercises** to:

- Provide students with a basic core of theoretical literacy that allow them to continue learning in a guided manner and by themselves when complexity increases.
- Guide students in discovering knowledge that complement the basic core. In the process through students are guided, a series of procedural skills must be developed that allow students to face the future.
- Develop a critical mind-set in the student when faced with simulation results.

Follow-up exercises must also be developed that present a small variation on the simulated circuit. These small changes would force the student to be aware of the overall functionality of the circuit and its possible usefulness. Exercises that present a change in the topology of the original circuit need also be proposed. These will develop a design attitude in students as well as the improvement of circuits based on those already known, providing students with an affirmation and confidence in the learning acquired or informing them of the concepts in which they are doubtful.

Six: Interactive student self-learning through multimedia systems

The use of multimedia systems drops time dedicated to learning by almost half. This is due to the blending of audio, video and animation in one media. Furthermore, it has been shown that interactivity between students and the application generates reinforcement, a greater and better assimilation of learning. When working with multimedia systems, retention and use of what was learned is significantly increased over a long period of time.

Additionally, as it is personalized learning, students can ask questions and explore without inhibitions, quickly and easily and with the advantage of being able to follow their own rate of learning with few distractions.

When using multimedia systems as part of learning, students feel motivated, satisfied and responsible for this process.

In different projects and research activities, including several Ph.D. Thesis and End Term projects, we have tested the “pedagogical” usefulness of these tools, including multimedia, videoconference and several other different aids, [8], [9], [10], [12].

Through the integration of simulation and multimedia tools, the learning process of Electronic Engineering is strengthened even more. This integration can be considered in different manners:

- Multimedia application to teach students how to simulate, so they can have a tool available that allows them to continue learning by themselves, in accordance with the spiral model of the learning process.
- Tutorial on the simulation tools used and their integration into a multimedia application.
- Multimedia application that acts as an instructor in guided discovery learning.

Seven: Relations and communication with other persons, organizations and groups

Current telecommunications systems make it possible for students to establish relationships with other people and institutions related to digital electronics over the *Internet*. Off-line through: Newsgroups, FAQs, ftp, e-mail, links, keyword searches on any issue or topic. On-line in chat groups, telnet, videoconferences, etc.

This student relationship and communication with other people and institutions allows them to maintain an active attitude, exchange knowledge and keep up to date on this rapidly evolving material.

PROJECTS PERFORMED BY UNED

To carry out this proposal, the **CAEE** Team (*Computer Aided Electronic Engineering*) of the Department of Electric, Electronic and Control Engineering of the UNED (Spanish University for Distance Education), has developed a text design with theoretical and practical content wherein resolved problems are included using current design methodologies, defining the systems using the hardware description language VHDL and analyzing them with computer simulation tools.

A Simulation Guide [8] has been prepared on digital format, titled "**Guide for circuit simulation**" that was published through the UNED publications service. This guide includes **user manuals and tutorials** developed for the simulation programs to be used, as well as freely distributed versions of these. The aim of this guide is to achieve the highest possible dissemination of computer simulation tools in the electronics field within the student environment at a price that is affordable for any student. It also aims to assure that the user or student does not waste time learning how to use them, as the objective is not in handling the tools but rather the benefits they can provide.

Likewise, a multimedia application has been developed titled "**Multimedia guide to Simulation**", (Figs. 1 and 2). It is designed as an introduction to the simulation process for electric and electronic circuits and to the interpretation of the results achieved in this process. The aim is to transmit to the end user (usually a technical student) basic knowledge of the simulation of electric and electronic circuits, work methodology and a critical and objective attitude towards the results obtained. This guide deals with topics that are general enough to allow the user to use any type of simulation tool.

FIGURE 1.
MULTIMEDIA GUIDE TO CIRCUIT SIMULATION (GENERAL TOPICS).

This multimedia guide, developed in Macromedia Director, allows a complete interactive and visual aid in the dissemination and easy start-up of simulation in the electrical and electronic circuit teaching. Developed following the blackboard metaphor it gains an intuitive start-up including a high number of multimedia formats, as they are texts, figures, sounds and music, simulation screens, Spice and Micro CAP simulations and URLs links.

Other included tool in this same way is an interactive prepared Power Point presentation, (Fig. 3), covering different presentations, simulations and tutorials since analog and digital circuit, text and simulation integration and general simulation overview.

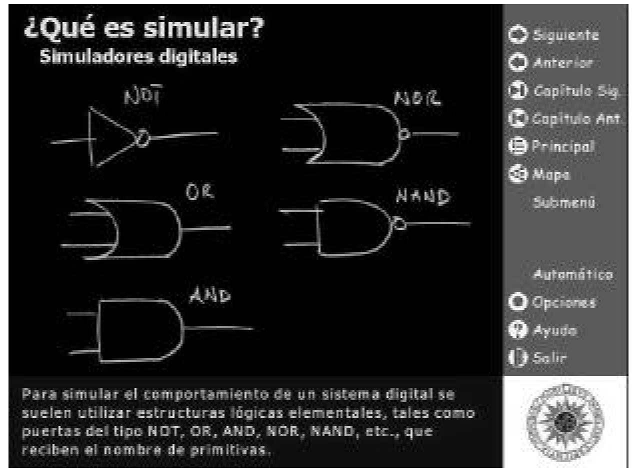

FIGURE 2.
MULTIMEDIA GUIDE TO CIRCUIT SIMULATION (SCREEN).

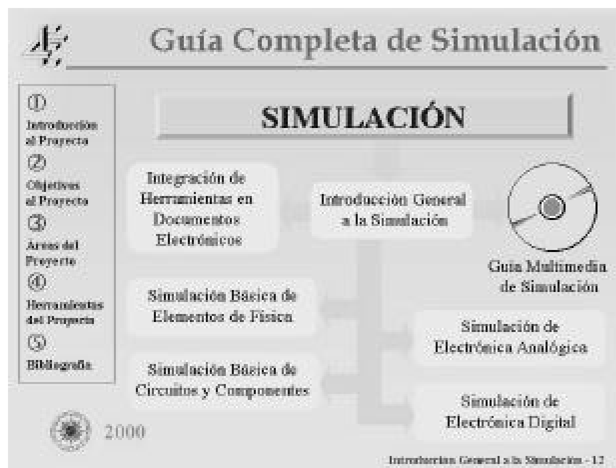

FIGURE 3.
POWER POINT INTERACTIVE PRESENTATION OF CIRCUIT SIMULATION .

FINAL OBJECTIVE

The objective of this curricular proposal is that, through the constructivist pedagogical model, students of digital electronics gain **theoretical and procedural** (know-how) knowledge from the beginning.

To that end, current design methodologies will be used as well as CAD and EDA tools that students will use during their career, such as: the systems modeling described in VHDL, computer assisted design, synthesis and verification of a system.

An additional aim is to provide students with multimedia applications as learning resource and access to information from other organizations, groups and people related to this topic through the Internet, together with the available evaluation and freeware simulation tools that sometime are difficult or weight time consuming to obtain from the Web.

CONCLUSIONS

Based on our experiences as teachers, we believe that uniting electronics theory, hardware description via VHDL, computer simulation tools and multimedia applications into a single work is very beneficial for the student.

We further believe that it is a field where new bibliography along these lines will appear in the near future.

Today's hardware description languages have opened up great possibilities in the modeling of systems oriented towards both simulation and synthesis. This is because they can be independent from CAD and EDA design tools and technology. Additionally, they allow systems to be defined by blocks (modularity) and with different levels of abstraction in each block.

The simulation of digital circuits has become a fundamental tool that allows theoretical knowledge acquired to be verified and experienced and allows more in-depth knowledge to be attained.

Within the framework of a constructivist model of the teaching-learning process for digital electronics, simulation tools and hardware formal description languages have a clear application in the "learning through guided discovery" focus. To that end, exercises and practical cases must be developed that, after a previous analysis, lead the student to the discovery of the digital circuit and its usefulness and limitations.

This leads to "significant learning", as the student will mange to expand and modify the knowledge acquired in theoretical analysis via description with VHDL and simulation. In this manner learning will be long-lasting, as the student will find a sense of the knowledge acquired and will always perceive close contact with reality. If simulation and multimedia tools are also integrated, the learning process of Electronic Engineering can be improved enormously.

Although hardware description languages such as VHDL are currently being increasingly worked with and used, it can be said that they could play an even greater role in teaching. For that reason and considering the advantages that their use provides to students, it is a topic that should continue to be researched and new developments should continue to be contributed.

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