

Teaching for Understanding in Electronics/Microelectronics by Training CAD Tools

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Introduction

In order to popularise technical professions (which are often considered to be unglamorous and too difficult [6]) teaching staff of technical universities should put teaching for understanding (TFU) concept up front. Especially it is important for electronics and microelectronics studies since we observe strong skills shortage in electronics/microelectronics industries [6]. Teaching for understanding in such technical subjects as electronics and microelectronics is rather pedagogic art than academic work. Main problem is how to present complex material of a high level of abstraction in a simple and understandable form [1,4]. That is why teaching staff looks for the ways to develop approaches which allow to present material with better understandings, to explain clearly, to find the analogies in order to clarify, etc. [2,3,5].

According to [3] understanding "...is a matter of being able to do a variety of thought-demanding things with a topic—like explaining, finding evidence and examples, generalising, applying, analogising, and representing the topic in a new way". There are four key concepts of TFU that give teachers tactics and strategy for enhancing their efforts to teach for greater understanding [2,7]:

Generative topics. Generative topic should be central to the discipline, accessible to students, and connectable to diverse topics inside and outside the discipline. If generativity of topics is insufficient the teacher should give the topic more generative cast by adding a theme or a perspective.

Understanding goals. A few specific understanding goals should be found from many different understandings which can be developed from each topic. These goals should be clear and should give the answers on "what students will understand?"

Understanding performances are defined as the heart of developing understanding. Most students' activities during learning process are not performances that demonstrate understanding. These performances are too routine to be understanding, they build knowledge, routine

skills but they do not build understanding. The teachers need to design understanding performances that support the understanding goals, so that the students will be involved into activities that ask them to generalise, find new example, carry out applications, find analogies and represent topic problems in a new way, from another point of view.

Ongoing assessment. The process of assessment should be more than just evaluation. The students need criteria, feedback, and opportunities for reflection from the beginning of and throughout any sequence of instruction [2]. The criteria should be clear, relevant and public and the feedback should be provided in order to inform students and teachers about both what students currently understand and how to proceed with the subsequent teaching and learning [7].

Together with keeping TFU concepts in our teaching activities we pursue a goal of raising the students interest in electronics and microelectronics studies using additional concept starting points of which include [1,4]:

- instilling the confidence into students that they will be able to understand very complex modern electronics and microelectronics;
- avoiding the fear of students before complex theoretical material;
- presenting complex material of a high level of abstraction in a simple and understandable form;
- finding and using the analogies for the explanation of different complex phenomena;
- keeping the students interest by teaching training material in an active way.

Our teaching experience shows that significant efforts, inventiveness, and pedagogic art are required to adhere the "teaching for understanding" concept in electronics and microelectronics education. Inestimable helper for us in this work is the development of the computer-based systems for education and training in electronics and microelectronics. Fortunately modern software and hardware tools allow to create very interesting and useful computer-based training systems in

different subfields of electronics and microelectronics.

In this paper we present filling of learning process by teaching for understanding properties using developed open training software tools for studying electronics and microelectronics, namely for studying in the field of computer-aided circuit design.

Getting knowledge using open CAD systems

Recently the software market in electronics and microelectronics has been satiated with different CAD tools and systems for analog and digital circuit design. Specialists in the field of circuit design should be able to make use of such systems. Therefore it seems natural that technical universities and other higher educational institutions that train future specialists in the field of electronics and microelectronics try to use modern CAD tools in their teaching process. These CAD systems are being successfully applied both in industry and in training.

However, for a student modern CAD systems are so called "black boxes". They are completely locked. So they do not reveal either the specific features of their own software, algorithms, methods, models and techniques used, or specifics of the programs caused by the design object (in this case - by electronic circuit, IC, VLSI). Because of the non-openness of the commercial systems the efficiency of their use for training purposes is not satisfactory. They are open systems that are necessary for teaching process.

We state that the students cannot be trained on the basis of inaccessible and locked up "black boxes". In fact the students cannot gain access to knowledge and experience concentrated in modern CAD systems. The skills obtained from using such systems in training process do not build understanding. This is to some extent a philosophical problem. If the approach does not change our students will be like the characters in the famous science fiction story by I.Asimov "Profession" [16]. They got their knowledge artificially, they did not know the source of it and therefore they were not able to deepen their knowledge and to perfect skills.

We consider it necessary to have some open systems filled with training components in modern software market in circuit design. Being given systems like these the students will be able to study the peculiarities of the software development of such systems (including algorithms, methods, models, etc) and their industrial analogues. In future when former students become engineers and designers they will be able to apply their knowledge and skills for the development of new CAD systems and for design of new circuits.

We suggest that open training system that teaches circuit designers has to agree with the following principles [8,10]:

1. *Openness principle* - completely open access to all the system components including the source texts of programs in order to have the possibility to introduce the change and to recompile the program.

2. *Correspondence principle* - training system has to be brought into line with similar industrial systems. That principle includes: a) functional correspondence (training system is to solve the same tasks as its industrial

analogue); b) linguistic correspondence (data description language, control statements and output data are to conform with the form of input/output data presentation in industrial circuit design systems).

3. *Teaching principles* are the main principles for training system. They include:

3.1. *Visual teaching principle* - training system should demonstrate how the circuit mathematical model is formed, how the input data are processed, how the algorithms work, what are the circuit diagram and the companion models associated with the elements for each method and so on.

3.2. *Choice principle* - training system should contain: library of different algorithms, methods and programs for solving one problem; different models of the circuit elements. There should exist a possibility to choose one of these models, algorithms, techniques, etc. and one should be able to run different programs (parallel or serial execution) when solving one task.

3.3. *Comparative evaluation principle* - when different algorithms are parallel or serial executed there should be a possibility, firstly, to compare their efficiencies - time and memory expenses, convergence of the algorithms; and secondly, to compare the accuracy of different models of the circuit elements.

3.4. *Investigation principle* - training system should enable students to carry out step-by-step investigation of the algorithms work and programs execution.

3.5. *Viewing principle* - when solving one of the tasks the possibility should be provided to look at the algorithms flow charts, to look through the source texts of programs realising algorithms that are being currently used, etc.

3.6. *On-line help principle* - student can use Help at any stage of work with any task.

The use of the above mentioned principles allows us to successfully develop open training software tools. Our teaching experience shows that using such tools in the teaching process provides better understanding of complex material. These tools are very popular among students.

Open Circuit Design System

The circuit design system "Micro-PC" presented in this paper is an example of the open training system. This system is destined for the teaching courses "Circuit Design and Analysis", "Circuit Theory", "CAD Systems for Circuit Design". Training system "Micro-PC" was designed as MS Windows application with graphical user interface (GUI). Figure 1 visualises the concept of GUI development that realises the dialogue with the system in such a way that it is quite understandable for the user [9]. "Micro-PC" includes solving the problems of circuit simulation, parametric optimization, tolerances assignment, development of circuit simplified models, providing the manufacturability, etc.

A special attention in the developed system is paid to the circuit analysis because considerable experience has been gained in this area; various methods, models, algorithms and programs have been developed. There are different algorithms for solving the same problems, e.g. integration algorithms used in transient analysis, different

transistor models, etc. The specific character of the design object (electronic circuit) has resulted in emergence of some original techniques, programs, adaptive algorithms. For example, sparse matrices technique with its different algorithms of optimal node renumbering, algorithms of LU-decomposition, programming of sparse matrices should be considered as the classic illustration of adaptive algorithm taking into account the specific features of the object of design i.e. the structure of electronic circuit.

Including in open system existing different methods, algorithms, models gives students a possibility to study the basics of circuit analysis and design and to use the acquired knowledge in the field of electronics and microelectronics or even in other fields by analogy.

The developed circuit design training system "Micro-PC" agrees with the proposed principles (see previous section).

According to the 1st principle this training system solves all typical tasks of circuit design. For example, during circuit simulation students may perform next typical analyses: DC analysis; AC analysis; transient analysis; sensitivity analysis; analysis of the influence of the temperature of environment; worst case analysis; insertion

or alteration of a circuit element; etc. The circuit description, control statements and the form of input data presentation are just traditional and similar to those used in PSpice [6]. Together with standard control commands .DC, AC, .TRAN, .TEMP, etc, which are used in industrial programs, "Micro-PC" has special set of training control operating statements. The example of set of traditional and training control statements of the "Micro-PC" circuit design training system is presented in Figure 2.

In accordance with the 2nd principle "Micro-PC" is a completely open system.

Graphical user interface of "Micro-PC" is developed to conform with the principles 3.1-3.6 which we consider the most important for training system development. According to the principle 3.1 special attention is paid to the formation of circuit mathematical model. Special control statement .PREPARE allows to visualise and to investigate the circuit data processing, the work of program realising sparse matrices technique, the peculiarities of programming of sparse matrices, the process of forming nodal admittance matrix and the structure of this matrix, the work of the algorithm of optimal node renumbering.

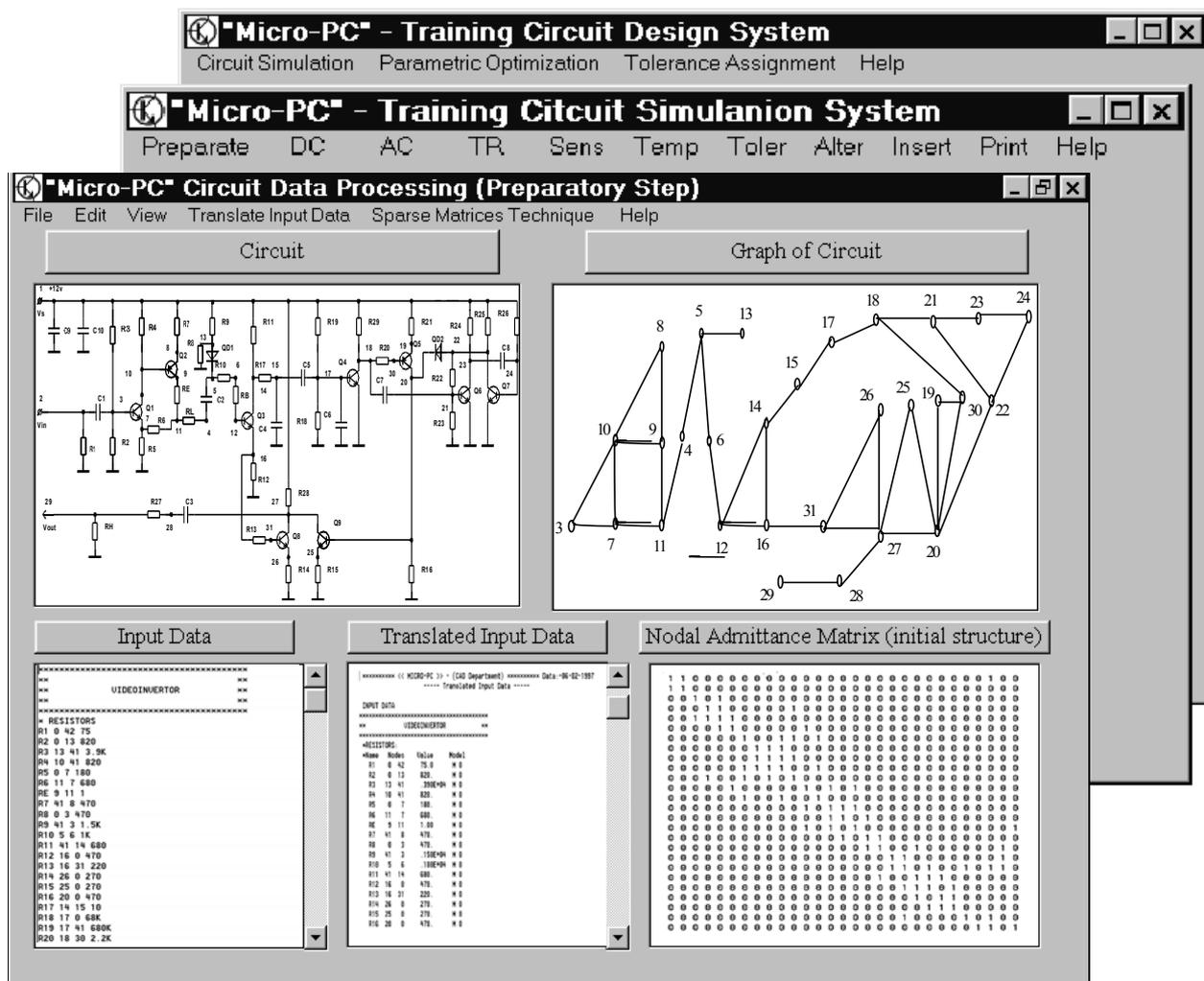


Fig. 1. GUI of "Micro-PC" circuit design system

This software tool should be open for the students, and the students should have the possibility to change, to improve or to develop themselves some parts of simulator (to realize certain kind of analysis), to recompile the system and to check it.

When planing understanding goals we stick to the opinion that understanding the nature of processes proceeding in the circuits is impossible without understanding of the mathematical tools describing these processes.

On the one hand in order to avoid the fear of students before complex theoretical material and to instil the confidence that they will be able to understand this material we state that the basics of electronics lies in one basic law and everyone should know it. It is the Ohm's Law. To our mind, to learn the foundations of electronics, it is necessary to know and to understand the Ohm's Law and to be able to think logically. Hence, we propose the formula of success in learning basics of electronics: $S = O + L$, where S - guaranty of success in learning of basics of electronics, O - knowledge and understanding of the Ohm's Law; L - ability to think logically [4].

On the other hand understanding not only the nature of circuits behaviour but understanding the mathematical basics of circuit theory as well is the guarantee for students to become highly qualified specialists. We maintain our opinion by expressive formula of G.W.Leibniz (it means that in accordance with God's calculation, the world is designed). If we paraphrase this sentence for our case, we may say that "how the mathematical models of the circuit is analysed, so the circuit operates" or in other words, "if the circuit is hard for analysis, the alive circuit will be heavy in functioning". For instance, we consider that the main advantage of circuit nodal analysis is that it reflects the nature of circuit behaviour: if the circuit is correctly designed, in general we have no problem with its analysis; if we have convergence troubles - you should look for the gaps in a circuit. Obviously the better understanding of mathematical tools of circuit theory will be provided if the students have the possibility to look inside the process of mathematical model formulation, to look and to investigate the performed algorithms of analyses. Thereto, better understanding will be provided if the students have the possibility to realise themselves certain method or algorithm, model of elements, to include it into open circuit simulator and to check it. "Micro-PC" allows to do all these things. In our learning process we pursue a goal to teach the students not only to analyse the existing circuits, but also to design circuits (to perform structural and parametric synthesis of a new circuit) with their own hand. To do this the students should understand the nature of circuit behavior and mathematical tool for the description of processes inside the circuit.

Open training system gives the best possibilities for the design of understanding performances. Such open system with full access (with access up to the source text of programs, with possibility to add some parts, to introduce changes and to recompile) allows to involve students into activities where they may create something new (new circuit, new models of devices, circuit macromodels, improved algorithm or methods, etc.) by generalising, expanding and reshaping the information

given, and apply what they already know. Students analyse the circuits by use the set of training control commands like *.PREPARE*, *CHOOSE*, *.COMPARE*, *.S-b-S*, *.LOOK* that provide the possibility to look inside the mathematical process of circuit simulation and design. At the same time they can introduce any change in models, methods, algorithms, etc. Students also try to design new non-standard (special purposes) analogue circuit.

Students are involved into such activities as the development circuit simplified models. To effectively solve the tasks of multi-objective parametric optimization of the circuits we proposed and successfully used the approach for the development circuits factorial models on the basis of factor experiment design with the full circuit model [13,14]. In our learning process we try to teach students to develop the circuits simplified models which can answer the questions put in the considered problem but do not mimic the real circuit behaviour. The motto of such activities is a quotation given by A.Einstein that "everything should be made as simple as possible but not simpler". We try to explain that sometimes very complex non-linear processes may proceed inside of the circuit, and the circuit will be too complex for simulation, but circuit output parameters of interest can be successfully approximated by simple polynomial dependencies. When the students developed simplified models of circuit, they should make decision themselves about models adequacy and about applicability of these models in the process of circuit design. Our training system "Micro-PC" (which includes the subsystems "Factor" for development of electronic circuits simplified models on the basis of factor experiment design [15]) allows to do it. Such activities give the students understanding that correct interpretation of the results of factorial experiments is a guarantee of successful application of circuit factorial models.

Another understanding performances directed to solve the tasks of circuit design process are developed for the students, and their performing is provided by "Micro-PC" open training system. For example, they are: evaluation and providing of circuit manufacturability and electro-thermal compatibility, tolerance analysis and assignment, sensitivity analysis and estimation of circuit vulnerability to local temperature influence, parametric optimization and synthesis, etc.

In the course of learning process the students investigate and try to improve a few standard complex analogue circuits and develop simple non-standard analogue circuit with special purpose. The results of simulation of the investigated and designed circuit by "Micro-PC" are compared with simulation results obtained by P-Spice simulator. Criteria for ongoing assessments are the comparison of the obtained results and degree of their matching. The designed simple non-standard analogue circuit usually is breadboard because only practical experience may be more useful criteria of truth. Students share the results of their design with one another for feedback and critique.

Conclusions

Intuitively every good teacher tries to teach for understanding. But for some subjects the teacher needs

auxiliary tools in order to realise concepts of TFU. It is just a matter of electronics and microelectronics studies. That is why "Micro-PC" system was developed. It should be noted that any industrial CAD system can be supplemented with teaching elements in the same way as the presented system "Micro-PC". To do this the proposed principles of development of the open training systems should be used.

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Analizuojamas elektronikos ir mikroelektronikos mokymo koncepcija. Tai yra daugiau pedagogikos menas nei pedagoginis darbas. Koncepcijai įgyvendinti reikia didelių dėstytojų pastangų ir išradinumo. Taigi čia į pagalbą pasitelkiamos atviro tipo mokomosios APS. Nagrinėjama tokių sistemų taikymo būtinybė. Suformuluoti pagrindiniai jų tobulinimo (eksploatavimo) principai. Pasiūlyta atvira „Micro-PC“ elektroninių schemų projektavimo mokomoji sistema. Parodyta, kaip pasiūlytoji programa palengvina dėstytojų darbą, įgyvendinant mokymo ir suvokimo koncepcijas. Il. 3, bibl. 17 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

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The realization of teaching for understanding concepts in electronics/microelectronics studies is considered. Teaching for understanding in electronics and microelectronics is rather pedagogic art than academic work. Significant efforts and inventiveness are required to adhere the "teaching for understanding" concept in these subjects. Inestimable helper for the teacher in this work is the development of the computer-based training systems. The necessity of the open system for teaching purposes is motivated. The basic principles of training system development are suggested. We present circuit design training system "Micro-PC" based on the proposed principles. This system allows to realize easier main concepts of teaching for understanding.. Il. 3, bibl. 17 (in English; summaries in Lithuanian, English, Russian). Il. 3, bibl. 17 (in English; summaries in Lithuanian, English and Russian).

М. Блызнюк, И. Казымыра. Преподавание для понимания в области электроники и микроэлектроники с помощью учебных САПР // *Электроника и электротехника.* – Каунас: Технология, 2004. – № 6(55). - С. 14-19.

Рассматривается подход, реализующий концепцию обучения для понимания в области электроники и микроэлектроники. Преподавание для понимания в этих областях представляет собой в большей мере педагогическое искусство нежели педагогическую работу. Реализация концепции требует от преподавателей значительных усилий и изобретательности. На помощь приходят учебные САПР открытого типа. Обоснована необходимость использования таких систем и сформулированы основные принципы их разработки. Представлена разработанная открытая учебная система проектирования электронных схем "Micro-PC". Продемонстрировано каким образом предложенная система облегчает работу преподавателей при реализации концепции обучения для понимания. Ил. 3, библи. 17 (на английском; рефераты на литовском, английском и русском яз.).