Microelectronics Education in Europe in 21ˢᵗ Century

Slavka Tzanova
Microelectronics Department
Technical University of Sofia
Sofia, Bulgaria
slavka@ecad.tu-sofia.bg

Attila Géczy, Oliver Krammer, Peter Martinek
ETT
Budapest University of Technology & Economics
Budapest, Hungary
{geszy, krammer, martinek}@ett.bme.hu

Zholt lyefalvi-Vitéz
Lightware Ltd.
Budapest, Hungary
illye@e ett.bme.hu

Mile Stakovski
FEIT
Ss. Cyril and Methodius University
Skopje, FYR Macedonia
milestk@feit.ukim.edu.mk

Rosario Gil, Manuel Castro-Gil
IEEC
Universidad Nacional de Educación a Distancia
Madrid, Spain
{rgil, mcastro}@ieec.uned.es

Norocel Codreanu
CETTI
Politehnika Bucharest
Bucharest, Romania
norocel.codreanu@cetti.ro

Abstract—**This paper presents some results of European projects for improvement and innovation of engineering education. It summarizes the application of performance support systems, previously used only for company training, in higher education and discusses its advantages. The development of distributed in four European countries performance-centred learning system for information technology, telecommunication, and microelectronics is also presented. As the practice in engineering education is crucial, virtual laboratories with demonstrations, animations and simulations were developed as well as laboratories with remote access to real experiments. Finally, our recent work on the creation of microelectronics Cloud system in nine European countries is presented by an example of building cloud nodes at an installation site.**

Keywords—engineering education; microelectronics; international collaboration, open educational resources; educational clouds; business-academia collaboration.

I. INTRODUCTION

Micro- nanoelectronics is the most rapidly developing science and it is the ground for the e-economy and the e-society development. So, the continuous training is crucial. But the science is so multidisciplinary and it requires very expensive equipment that few individual research institutes, laboratories or companies that can respond to the challenges of the most rapidly developing science. In nano-era the enterprises, higher education institutions and research institutes have to collaborate in research and education and this is the key factor to strengthen the European research and development potential" [11].

This paper makes an overview of our seveteen year experience in international collaboration in sharing resources, laboratories, teachers and students for improving the education in the most rapidly developing science – microelectronics.

II. PERFORMANCE SUPPORT SYSTEMS IN ENGINEERING EDUCATION

"Focusing on learning or knowledge transfer rather than performance results in people who know what to do but never do it" [1]. So, learning must be linked to task performance, shared with the entire institution, and then cycled back into the next iteration of training. In this paper we summarise the results of some projects in which we developed performance support systems for engineering education.

Moreover, in the computer-based training, usually the expository deductive instructional strategy is used. In the engineering education complex cognitive skills should be trained. Engineering involves the use and application of problem-solving skills, e.g. skills for finding solutions, making decisions, and thinking effectively. So, the instructional strategies and tactics for higher-level skills should be appliedin such a course design [2].

We developed, tested and implemented the methodology of Internet-based performance-centred instruction (IPCI) in a number of European higher education institutions, vocational training organisation, small and medium enterprises (SMEs) within four pilot projects. [3].

The Internet-based performance-centred instruction transforms the traditional teaching systems into the closely linked to the job learning. [5].

A. mSysTech project

The "e-Training Microsystems Technologies" (mSysTech), project, was a successful European project funded by the European Commission, in the frame of the Leonardo da Vinci programme, which was destined to support the Life Long Learning process, offering a natural move of traditional university education to job-related learning [4]. Partnership between small and medium enterprises (SMEs) and universities, for delivering training in this area, had a "high importance for the European competitiveness on the world market of electronics" [5].

Based on the mSysTech project, the Romanian engineers and other specialists involved in electronics, microelectronics and microsystems "had the opportunity to be in contact with the latest developments in these very dynamic fields and had access to practice oriented, vocational training courses destined to increase the knowledge level" [6]. Figure 1 presents two panels of demonstrators developed during the project.

Because microsystems are developed based on the highest level of research, a continuous training is essential. The mSysTech project was aimed at "adapting existing scientific resources and developing new courses for the lifelong

performance support systems in microelectronics and microsystems, for the needs of the European SMEs, vocational schools and universities".

In Romania, for example, the impact was very high and new national projects were established after the end of mSysTech, based on the experience gained by the UPB-CETTI partner and based on the developed scientific resources.
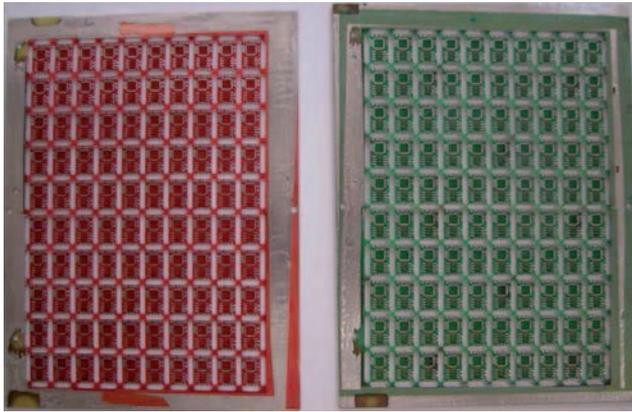

Fig. 1. Panels of demonstrators developed during the mSysTech project.

The most important outputs of mSysTech were the four courses developed: "Microsystems Design", "Photomasks and Mask Data Preparation", "Packaging Technologies" and "Thermal Management". As only one example, the "Photomasks and Mask Data Preparation" course, developed by the specialists of Xyalis, an innovative French SME (http://www.xyalis.com/), which was partner in the project, was very new at that time, being of a crucial importance for the developers of chips/dice and microsystems.

Regarding the demonstrators, some examples are presented in figure 1 (panelized printed circuit board structures of them). They were designed and produced in the frame of the project, using both discrete devices and integrated circuits.

The electronic modules were of low complexity, but the trained staff from vocational schools, academia and industry had the possibility to follow the full design and manufacturing flow, using advanced freeware design software systems and modern technological facilities offered by UPB-CETTI research center.

Figure 2 offers the image of another demonstrator, after assembling and testing procedures. The MSysTech text, placed as silk-screen on the top of the module, emphasizes the acronym of the Leonardo da Vinci project and its support for training people in gaining job-related skills and expertise.

The image from figure 2 underlines the necessity of mixing theoretical knowledge with practical engineering expertise in the today microelectronics field, in order to produce real microsystems or microelectronic modules and to satisfy the requirements from the industry, which highly needs experts in applied engineering, not only in mathematics and theoretical science.

B. SCOPES projects

"Skills Development for Young Researchers and Educational Personal in Nano and Microelectronics Curricula: implementation of Methods for Bilateral Knowledge Transfer between Universities and SMEs" was a SCOPES project (2011-2014, SCOPES IP, Swiss National Science Foundation) between the University of Applied Sciences Western Switzerland - Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud, the Ss Cyril & Methodius University Skopje (Macedonia) and the Technical University of Sofia (Bulgaria). The main objectives of the project were: (1) "adapting the Swiss universities' good practices in teaching and training micro- & nanotechnology to the specific needs of the Eastern European partners to improve their educational models and approaches (2) development of a new curriculum and script in nanoelectronics including application examples to improve and modernize the education and training in high technologies in Macedonia and Bulgaria and (3) training young scientists in engineering and renewal of the infrastructure for research and teaching in micro- an nano-electronics to strengthen the Macedonian and Bulgarian universities' research and teaching performance" [8].

To transfer knowledge between higher education institutions and SMEs, practical exploration tasks and laboratory training experiments were implemented as methods in our curricula. In the laboratory training experiments the following scenarios were used: (1) Our students worked on the experiments to understand general principles at the nano and micro scale using different components and devices. (2) The students worked on and completed instrumentation studies for better understanding of measurement principles and of the role of instruments or devices components (3) Students also did measurements with faulty parameters that give bad results in order to be able to find possible origins of errors and develop their own approaches for technological process improvement [7,9].

With the use of application examples, pilot training sessions, various exploration tasks, or visits of companies, a close link to the labor market was established. Such methods were successfully implemented in all of the three partner countries in order to innovate the local curricula in the fields of electrical engineering, mechatronics, microelectronics, and nano- and micro-technology.

Fig. 2. Finished demonstrator, after assembling and testing.

III. DISTRIBUTED SYSTEMS

The results of the development and implementation of IPCI in polytechnic higher education institutions and in vocational education across Europe were very encouraging. However, we identified the following specific technological problems due to a centralized system: problems with the access to the data-base in case of bad or missing Internet connection with the server; need of specific coding table on the corresponding developer's computer for inserting multi-language content to the data-base; security problems; very big amount of information and need of specification of servers in language and subject matter [10].
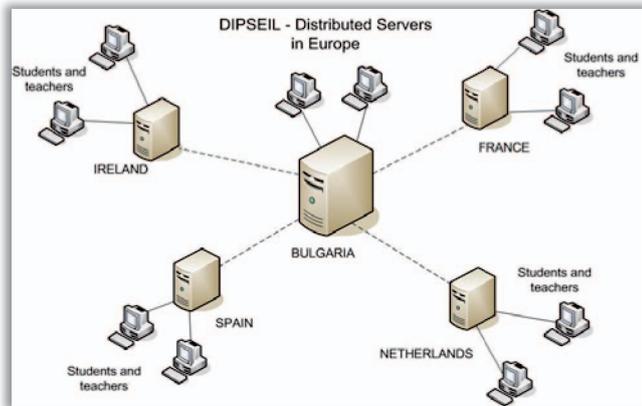

Fig. 3. Distributed learning management system [10].

In order to address the problems identified in the practice of applying IPCI systems, a distributed performance-centred system for microelectronic, informatics and telecommunication education has been designed, developed and implemented, and five IPCI servers have been installed in Bulgaria, Spain, the Netherlands and Austria (Fig. 3). In addition, a "pool of learning resources on IPCI database in four different languages was provided" [10]. The next step was the development of a distributed learning systems in nanoelectronics within the Train_Nanoelectronics project [11].

The key elements of the distributed Internet-based environment for engineering education were: multilanguage, multi-subject and adaptive system model, for teachers and students, in wide educational aspects:
•   in the new system, the distributed cognition and distributed learning were underlying concepts as a next step in the implementation of performance support systems. We provided learners the opportunity not only to study a particular content but also to interact with peers, instructors and other experts;
•   it was the first in the class of performance support systems attempt to realize the ideas of adaptive distributed learning;
•   the system adapted the content not only to the level of prior knowledge as most of adaptive system do, but included in addition learning styles, cognitive modalities and cognitive efforts as well;

•   the two projects, DIPSEIL and Train_Nanoelectronics validated a procedure for determining the effect of a distributed performance support system for individualized learning [12].

IV. VIRTUAL LABORATORIES AND REMOTE ACCESS LABORATORIES

E-learning course development and delivery software is becoming common in many areas of education but the facilities provided by such systems do not support practical laboratory work.

The accelerated pace at which both the informatics and telecommunications worlds are advancing, along with their always increasing availability, are creating a new relationship between the teaching process and the way students are learning. The experimental work is a vital component of science and engineering teaching at all levels.

In 1996-1999 the MODEM project was the first attempt to develop a telematics based European wide infrastructure and organisation to support education and training in microelectronics. The project was very innovative and successful but after the end of the European financing there was continuation. Here we present some results of European projects for development of virtual laboratories and remote access to real laboratories.

A. Virtual laboratories of BME

The competence of BME-ETT (Budapest, Hungary) in virtual laboratories is shown by almost two decades of experience. Microelectronic technologies, the steps of the processes and the complex instrumentation need careful and colorful introduction to the students. Virtual presentation and animation of the given processes may help better understanding of the technologies, where the smaller details can also be highlighted and shown without the need of a real life visit and contact experience of the expensive (and often hard to reach) industrial instrumentation. The "Technology of Electronic Products" course provides a comprehensive overview of microelectronic devices, components, mechatronic, optoelectronic and other modules. It also presents the structure of electronic equipment including their manufacturing, maintenance and assembly technologies. Virtual laboratory classes are continuing with "Assembling and Inspection Technologies". The lab-tour provides insight with reflow soldering, steps of stencil manufacturing and designing, automations of the processes, thermal profiling, and failure troubleshooting. The inspection technologies (such as automated optical inspection and X-ray) are also described in deep details and with virtual animations. The virtual learning experience also includes the wide field of sensors and the micro scale of MEMS devices with multi-media enhancement. The animation of the micro scale structures and sensor elements help to develop the knowledge on the working principles on an extensive range of devices, also highlighting the application possibilities, and the potential connecting points of the two topics. Figure below shows an example of an interactive course presenting the working principles of different thermistors.
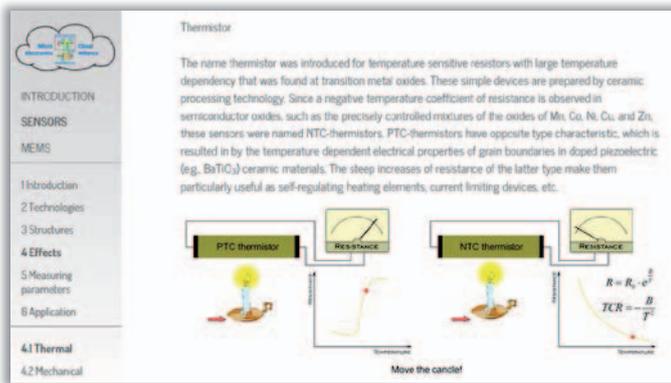
Fig. 4. Interactive presentation of a sensor element in a virtual lab: PTC and NTC thermistor characteristics change with the movement of the candle.

B. Remote laboratories of UNED

The educational model has evolved along with technology and the needs of people. Nowadays it offers hundreds of different courses, each of them having its own methodology. Thus, universities and training centers have renewed their courses and educational resources in order to be more competitive. Today, courses have very specific characteristics; among them we can highlight: open courses; easy environments where they are hosted; dynamic and varied contents, allowing interaction between users without time limits or geographical restrictions; virtual and remote activities.

UNED – Spanish University for Distance Education – has developed a varied number of open courses and MOOCs for different profiles, such as: students interested in and curious about engineering; those who start working or would like to strengthen their knowledge beyond their local boundaries; and, finally, people who want to acquire new knowledge.

In general, innovation in these courses lies on the integration of a remote laboratory (VISIR, Virtual Instruments System in Reality). Even very young students can work with real instrumentation. Thus this remote laboratory has been included as a key tool in the learning process of pre-university students.

VISIR is used in these courses, as a remote lab for experiments on electric and electronic circuits. This remote laboratory was developed by Blekinge Institute of Technology (BTH) and nowadays it is being used in several universities worldwide [13].

This remote lab is released under a GNU GPL license. Basically, the procedure is: First, a VISIR website, that will be the "Web Interface"; A client logs generates a session cookie, that will be stored in the "Measurement Server" for authentication; the whole lab workbench is provided through a HTML page as an embedded object; Finally, a stand-alone equipment controller written in LabVIEW will handle all the instrument hardware with a relay switching matrix, which we will call "Equipment Server".

So, what happens with the traditional equipment? Function generator, oscilloscope and so on will be replaced by an equipment platform. This kind of platform is perfect for remote control, using: PXI (PCI eXtensions for Instrumentation), LXI (LAN eXtensions for Instrumentation) and GPIB (General Purpose Interface Bus) [14]. In the case of the traditional instruments, VISIR will use modules cards NI PXI-Instruments, which are manufactured by National Instruments.

The relay switching matrix, which was mentioned above, is where the components are allocated and connected to the modules cards NI-PXI. The design of a circuit is possible by means of relays which act as a switch between nodes and components. At the same time, each NI PXI-Instrument is also connected to the relay switching matrix. Figure 1 shows VISIR in UNED with all the modules cards NI-PXI and the relay switching matrix.
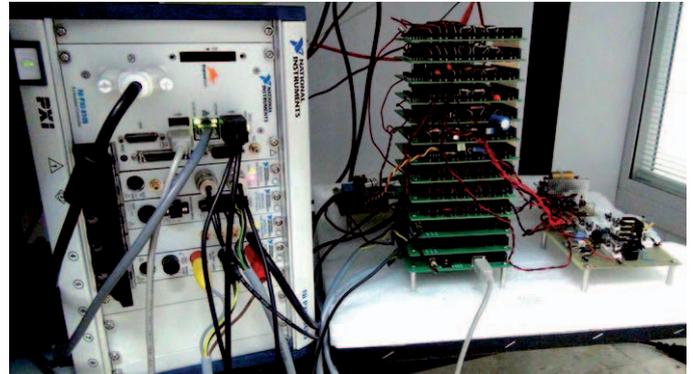

Fig. 5. Remote laboratorie of UNED: VISIR.

The interaction and communication between students and the workbench of an experiment are the only difference between remote and traditional labs. The best feature of the remote labs is the availability themselves, there is no temporal nor geographical restrictions [15]. Of course, there are more advantages when it is used remote labs instead of traditional labs; such as: low maintenance cost; no need for assistance during students' experimentation; no associated risks for students and instrumentations. However, they have limitations, that they are not found in the traditional labs; such as: the degree of freedom in the design of experiments.

V. MICROELECTRONICS CLOUD SYSTEM

There has been an active research in the field of electronics technology in the last decades. This improves the education especially e-learning at this field as well [16], [17]. E-learning courses involve almost every kind of topics including Microelectronics. Several students can be reached even from big distances this way.

The Erasmus+ Project called MECA (MicroElectronics Cloud Alliance) aims to build and host a Europe wide cloud platform to support the education at the field of microelectronics. Cloud architectures have three different basic types: Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS). After the detailed evaluation of the needs the IaaS approach was selected in the project which means the creation of a private cloud upon resources of several partners across Europe. To lower initial costs the product CloudStack from vendor Apache was selected

which is a solid but free product supporting any kind of hypervisors [18].

First the building of the cloud nodes at the installation sites at the partners had to be done. In Hungary, BME-ETT and Lightware Ltd. were responsible for this. The infrastructure of one mCloud node consists of the following main components:

- The management server is responsible for the control, customization and overall management of the infrastructure including the creation, starting, stopping, etc. of the VMs. The management server also offers the GUI for the administration of the system.
- The storage server is used for holding the data and VMs (including the essential system VMs and templates).
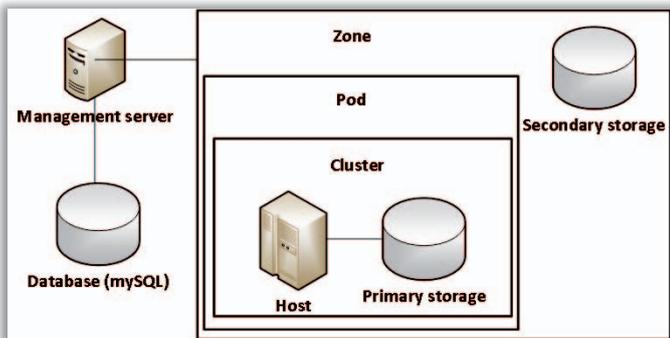- The computing nodes are the actual hosts, resources for running the VMs.

Fig. 6.   CloudStack basic installation architecture [19]

The high performance and scalability is planned to be achieved by integrating the hardware and software offerings of several project partners. This means, that only a basic installation of the Apache CloudStack consuming only a low amount of resources is required at each participant. The mCloud will be realized by the so called "region concept" of the Apache CloudStack. This is a simple integration of basic management data of the CloudStack Zones i.e. the nodes of the project partners. With the synchronization of user data, privileges, passwords etc. system administrators can enter the management console of every node and access all of the resources of the mCloud system.

The resources of the mCloud are consumed and offered by the virtual machines (VMs). VMs can use different amount of the different resources like computational capacity (defined mostly in the number of assigned processor cores and their maximum clock speed in GHz), memory (defined in GBytes), network usage (mostly number and type of network controllers and allocated bandwidth), etc.

VMs are created upon the so called VM templates in the mCloud. As the architecture provides a separated storage for templates, hence the creation and startup of new VMs can be performed easily. However this should be done by the cloud experts involving the owners of the specific e-learning courses which the given template is created for. The producing of the actual VMs for a given e-learning course may be already done by the lecturer of the given course.

The created mCloud system is highly scalable and fault tolerant as any distributed solutions. Furthermore the applied solution from the software vendor Apache is a solid tool providing support for the integration of nodes at all the level of data, application and user interface as well. The available APIs makes possible to customize the system facilitating any further improvements in the future.

Experiments were performed in the pilot environment of the mClouds system. Eight system nodes are up and operational and successfully integrated. Sample VM templates are created and equipped with CAD tools and also the required e-learning course materials are provided by the partners of the project MECA. Currently some end-user tests are under preparation.

VI.   SUMMARY AND CONCLUSIONS

Ten years we devoted to develop and implement performance-centred approach in higher education, in-company training and vocational education. We started with IPSS_EE project [20], then continued with IPCI [21], with IPLECS [22], mSysTech [23] and SCOPES [24]. The approach of Internet-based performance support system for engineering education has been developed and implemented in Austria, Bulgaria, France, Hungary, Macedonia, the Netherlands and Spain. The pedagogical experiments returned strong positive results [27]. The experiment with control and experimental group has proven that the inquisitor-deductive approach used in IPCI for training higher order skills was more effective than the traditional expository inductive (lecture-practice-test).

Our research continued with the development of distributed performance-centred adaptive learning management system under IPCI project. Five servers have been set-up in four European countries and distributed curricula have been delivered. In the next project IPLECS, almost fifty performance-centred courses in five languages in information technology, telecommunication, microelectronics and electronics have been delivered. [28].

The feedback from the employers of graduated students was very positive but they expected their future employees being trained in more practical skills and that more laboratory practice was necessary [29].

To respond to the labour market needs and to the European "New Skills for New Jobs" strategy we designed the RIPLECS project [25], building on existing know-how transfer to create a remote access laboratories in multiple disciplines. The authors from BME and UNED presented in this paper their results in the development of virtual and remote access laboratories.

In our recent research, the Cloud computing was used for sharing server resources, both hardware and software, and it was also adapted for sharing e-learning courses. The developed and implemented in the "Microelectronics Cloud Alliance" project mClouds architecture enables the Europe-wide collaborative use of resources, including laboratory-experiments, using multiple Web servers in a common network topology [26]. Students have the opportunity to interact remotely with the experiments as they would do at the future work place. The courses were developed by instructors from different European countries. They could profit from the

advantage of running laboratory experiments and teach it and support the students in their native language and from their personal pedagogical point of view.

The results of the presented research and the systems developed have been successfully implemented in engineering education in the Austrian, Bulgarian, French, German, Hungarian, Irish, Italian, Macedonian, Dutch, Romanian, Spanish and the Swiss higher education institutions.

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