ISSN 0005-1144
ATKAFF 51(2), 166–173(2010)

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Teaching Electrical Drives and Power Electronics: eLearning and Beyond

UDK 37:004:621.313.3
IFAC 6.8; 2.8.3

Review

Today the education is influenced by eLearning facilities and the accent lies in skills and (deep) understanding rather than in knowledge. In the paper survey of the present state of development of eLearning in Electrical Drives and Power Electronics (ED&PE) is given. Problem based and project based education are the keywords for modern education. This gives to the student a very good knowledge in individual disciplines while integrating the disciplines together to a useful whole of knowledge and skills is difficult. Integrating the disciplines and finding new challenging examples and teaching methods is illustrated on example of an electrical drive for a hybrid car. The paper summarizes the results achieved in the development of multimedia based eLearning tools in the field of electrical drives and power electronics as well as distance and virtual laboratories. Finally many challenges for future development of the eLearning are listed

Key words: eLearning, Project oriented learning, Electrical drives, Power electronics

Obrazovanje u području elektromotornih pogona i učinske elektronike: e-učenje i više od toga. U današnje je vrijeme način obrazovanja pod utjecajem elemenata e-učenja pri čemu je naglasak više na stjecanju vještina i razumijevanju postojećeg sadržaja nego stjecanju stvarnoga znanja. U članku je analizirano trenutno stanje razvoja e-učenja na području električnih pogona i učinske elektronike. Obrazovanje zasnovano na rješavanju specifičnih i projektno orijentiranih zadataka ključni su elementi suvremenog obrazovanja. Oni osiguravaju studentima dobra znanja u pojedinim tehničkim područjima, dok je integracija tih područja u stvaranju cjelovitog znanja i vještina znatno složeniji zadatak. Integracija pojedinih područja i pronalaženje reprezentativnih primjera kao i metoda učenja prikazana je na primjeru električnog pogona hibridnog automobila. U članku se analiziraju rezultati postignuti u razvoju multimedijski zasnovanih alata e-učenja u području električnih pogona i učinske elektronike kao i učenja na daljinu te virtualnih laboratorija. Na kraju su navedeni prijedlozi za unaprjeđenje i razvoj novih alata u okviru e-učenja.

Ključne riječi: e-učenje, projektno orijentirano učenje, električni pogoni, učinska (energetska) elektronika

1 INTRODUCTION

Traditionally, in development of engineering education, the key objective was to enable a teacher to convey knowledge and insight to students. The main element of explanation was (and still often is) the lecture, in which the teacher explains, presents examples, shows calculations, discusses mathematical derivations, etc. The accent has been given to the oral communication supported by on-line hand written messages using the blackboard and chalk, or transparencies for overhead projector in a newer case. Today the education is influenced by emerging eLearning facilities and the accent lies in skills and (deep) understanding rather than in knowledge. In this respect, the eLearning plays an important role in education. In the paper, the development of eLearning in Electrical Engineering and its current state of the art are reviewed. Education in electrical engineering is changing towards paying attention to integration of knowledge areas and to development of skills for learning. The market expects universities to deliver professionals at an academic level, with skills for cooperation, communication, problem solving design and research. The curricula should be adapted to competence development and active participation.

The development in last years in education and particularly in the field of Electrical Drives and Power Electronics (ED&PE) can be summarized by the following six developments:

1. eLearning became mature and fully implemented also in the field of ED&PE.
2. The young generation has also changed. Nowadays they think in terms of bites and bytes but not in the

terms of energy and power although and the today's students are internet-minded.

3. Economical pressure (changing *homo academicus* to a *homo economicus*) caused decreasing amount of face to face education and practical work and increased competition.

4. Globalization has influenced also the education. All over the world the Electrical Drives and Power Electronics is educated from the same book and material with different results.

5. In spite of energy hype the field of ED&PE attracts still not enough students. Some possible reasons are the rather old fashioned image and the low visibility of the field. Steps have to be taken to increase the attractiveness of the field

6. ED&PE enters new areas such as sustainable power engineering and hybrid/electric car development.

These questions are addressed in the paper although not necessarily in the same order. Before survey of the present state of eLearning is given, the problem of integrating the disciplines is addressed.

The paper deals with and explain different levels of eLearning implementation related to the levels of learning - generally and specifically for field electrical engineering. At the end, there are shown our expectations in future trends of distance learning material development in electrical engineering higher education.

2 INTEGRATING THE DISCIPLINE

Most universities are using a traditional approach where a student goes through a huge amount of high-level courses supplemented with one or two small projects obtains a Masters degree when the exact number of credits is obtained. This will give the student a very good knowledge to the individual disciplines while integrating the disciplines together to a useful whole of knowledge and skills is difficult. Practical and soft skills are not really trained and complete for a graduate. Graduates have to be prepared for professional and research futures. In this decennium of rapid changes students need to develop life long learning skills as well. An alternative approach is to use a problem based learning (PBL) method either by the individual or by working in teams in order to extend the curriculum to other professional skills than the technical matters [8].

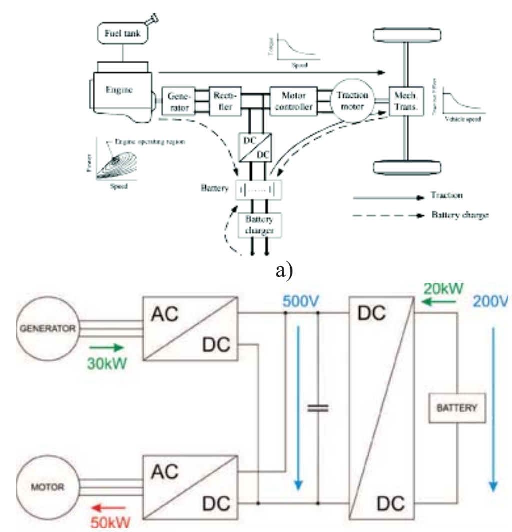
In next example such an example of successful integration of the disciplines together to a useful whole is given. The term "Electrical Drives" refers to systems with special characteristics that can be achieved only as a whole,

Fig. 1. Electrical subsystem of a hybrid car [16]

and can not be realized through other means. Previous remarks regarding integrating knowledge translated in a concrete specific example is shown next. Instead of teaching components of an electrical drive such as machines, power electronics and control, an integrated example is treated here. It is offered within the subject Electrical Drives for mechanical engineering students at the Delft University of Technology. As integrating example the electromechanical system of a hybrid car is studied (Fig. 1, 2).

This example is selected for two reasons. It allows to explain components such as AC and DC motors and generators and DC-DC as well AC-DC and DC- AC power conversion and place them in a single case study.

The second reason is attractiveness of the subject in the presence, hereby addressing the points 5 and 6 from the



a)

b)

Fig. 2. Electrical subsystem of a hybrid car

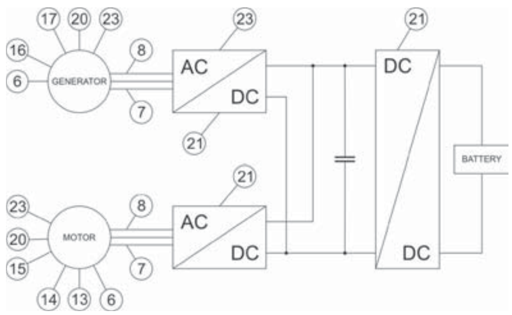


Fig. 3. Identified chapters from the book of Wildi

list of developments mentioned in the introduction. As a basic study material a book of Theodore Wildi: Electrical Machines, Drives and Power Systems, [17] is selected.

This book treats all mentioned subjects by classical way. In Fig. 3 chapters from the book of Wildi are identified and they relation to the treated example is defined. As an example - the chapters 7 and 8 treat about three phase networks, active reactive power and power factor.

All numbers in Fig. 3 refer to a specific chapter from the mentioned book. The treated example stresses use of bidirectional power electronic converters. To explain this aspect, two eLearning methods namely

1. Interactive animations and
2. Distance experiments are used in the way of problem oriented project learning.

As already stressed, in the past, the main objective of teaching consisted in acquiring knowledge by students and the assessment was based on testing whether the students can reproduce the acquired knowledge. Presently, the main objective of teaching is the development of student skills. This means that the teacher is a coach in the process of the student development. Obviously, this has its implications on assessment, as was discussed in [4]. In this work six levels (originally the Bloom's levels according to the author [4], revised in [5]) within the cognitive domain are identified. Taxonomical levels of intellectual behaviour important to learning are listed in [5].

The eLearning should not only follow the lowest step in the six levels of Anderson & Krathwohl pyramid but it has to aim to higher levels. The solution consists in implementing into eLearning also modern approaches such as *problem based* and *project based education*.

3 E–LEARNING

Concerning the eLearning, one of the first steps in using computers in education represented a *mechanical conversion* of traditional study materials *into an electronic form* and making them accessible to students, usually via a university computer network. The new materials were produced and distributed on PCs, but nevertheless, they proved to be unsuitable for working in electronic form. Their predominantly textual form directly predetermined them to the traditional form of study – reading from printed materials.

Other issues has focussed to the style of teaching under impression of extensive usage of multi-media like video-clips, audio or "slide shows" in the classroom or via distance (internet). The quality of picture and the flexibility open new prospects and make it particularly attractive. Their advantages to facilitate teacher's work are following: *interesting facilities* that *increase quality of pedagogical work*, *fast and easy reading*, *implementation of experiments, saving of time, repetition, elimination of errors and damages,* as well as the *reduction of students' and teacher's* stresses. The video have mobilized the interest of students but on other side its disadvantage consists in a possible passivity of the students.

A survey of phases of eLearning is shown in Table 1.

Table 1. Phases of eLearning

Phase of eLearning	Educational designs	Level of learning
Substitution	• eLearning portal course materials • interactive animations	up to remembrance and understanding
Transition	• distance experiments	up to analysis and evaluation
Transformation	• projects	up to creation and competence development

4 LEVELS OF E–LEARNING

4.1 Level 1: eLearning portals

Widget networking allows consumers to build personalized computer applications out of widgets, i.e. handy and compact software components exposed as fully functional web applications displayed in a web browser. Consumers build their own applications by interconnecting independent widgets into personalized workflows that deliver new value-added functionalities. The ultimate goal of consumer-driven personalization of network applications is achieved as an end result of a multi-tiered model shown in Fig. 2.

The eLearning technologies create *multimedia databases of knowledge* of an institution in the form of electronic courses available on arbitrary computers connected to Internet and they provide remote communication with teacher. The eLearning in a broader form can be defined as *ICT applications for education development,* *distribution, and management*. To facilitate the usage and availability of the learning material, special facilities, such as blackboard portal, are used. They allow easy communication between users, facilitate placing of the learning materials, assessment and evaluation as well as grade book. This way the educator uses the portal flexibly without an ICT specialist in between. In the eLearning development this is *the phase of substitution*. Communication about course materials and course information, even grades are to be found on the portal, but they have little effect on the educational habits [1]. Lately self and peer assessment enhance the possibilities together with plagiarism prevention software. However, these portals-programs are not creating a platform for advanced eLearning technologies such as animations or measurements.

4.2 Level 2: Interactive animations

Explaining of behaviour and teaching and of a technical system is often difficult because there are a large number of possible reactions of a system to parameter changes. If the same dynamics is presented in the form of a short movie, the dynamic system behaviour can be explained much easier in many cases. Animations during simulation open up new possibilities for teachers and enable a student to avoid passive watching the display at learning and pushes him to active participate in the learning process. Here, the utilisation of interactive animations in simulation enables to create a *virtual training environment*, partly replacing the physical laboratories. By interactive animations the levels of remembrance of knowledge and understanding are challenged.

The criteria for interactive animations are following:

- due to multi-dimensional character of the systems, a high degree of interactivity should be provided, e.g. if simulations or computer-animations are used, the students should have a possibility to freeze the time or even reverse the time so as to study the causal relation between different phenomena and states of the circuit under study,
- the eLearning supporting system should be developed in such a way that it would allow students to acquire a deep insight into the complex and dynamic interactions of a number of parameters,
- the eLearning system should be structured in such way that the learning proceeds with increased complexity (hierarchical approach),
- the system should give a qualitative impression of level of different quantities,
- the students should get motivation to study these systems in more detail, so as to become skilled in designing such systems themselves.

Finally, the system should allow a self-assessment of student learning and it should allow including *assignments* as well as individual *assessments.*

When e.g. studying a certain power electronic circuit, the first question of the student is always for the different current paths in dependency of the switching states and certain impressed currents and voltages.

With traditional teaching the current paths are drawn using different colours into some figures of power circuits, or the teacher's present slide-shows in the classroom. Here the approach of interactive animations is used. Different visualization principles for explaining power electronic circuits are summarized in [7]. To illustrate the ideas mentioned above, one example from module 3.5 (INETELE [7]) is shown in Fig. 4.

The square wave generation principle, shown in Fig. 4. presents a basic switching strategy used for high power converters. Detailed explanation of the circuit behaviour is contained in the associated secondary screen. The continuously running animation was replaced by a static one where the cursor (orange vertical line in the time diagram) that can be shifted in time by the lecturer. This solution gives a possibility to explain circuit behaviour given by switching states of the power semiconductor devices in the required time instant.

For the integrating example except of knowledge from electrical engineering also some knowledge from mechanical engineering and control theory is required. In the modules physical laws concerning various applications of motion are explained, further mathematical models of drive systems, block diagrams explaining system connections. Simulations and interactive graphs are widely used here.

It depends on the pedagogical skill of the animated screens developer – in order not to disperse the mind of the learner, the screen should be self-guided and to show the basic information only. Both screens in Fig. 4 and Fig. 5 (courses of variables – voltage, line current, motor torque, and speed at starting the motor supplied from the frequency converter) satisfy all such criteria.

4.2.1 Higher Order Learning Oriented Education

Interactive animations and simulations create a *virtual interactive training environment* that replaces partly the laboratories: they allow students to perform small experiments and provide system analysis. After the student learns system properties, the higher order learning should

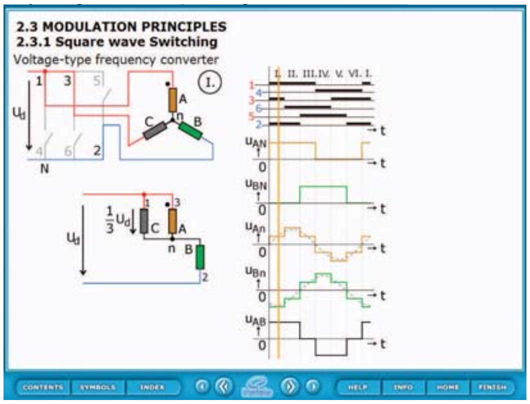


Fig. 4. Screen to demonstrate switching states in power electronics converters: square wave switching in the voltage source inverter

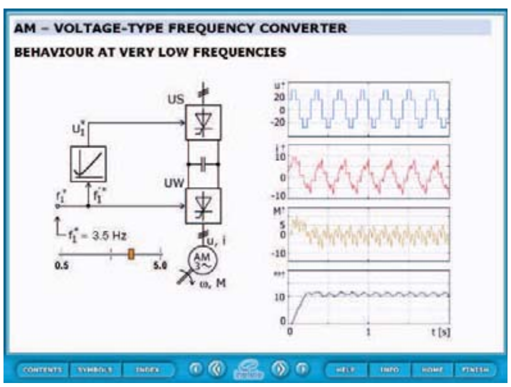


Fig. 5. Screen to demonstrate AC drive performance

follow (strongly required by the praxis): based of knowledge of components and subsystems behaviour he has *to perform synthesis* of the final system utilising advantages of computer processing and to design the system based on real (produced) components. The students although having good theoretical background, generally do not posses ability to apply fully their knowledge, e.g. to design new systems (in our case the electrical ones). By other words: there is missing a general approach to guide students in analyzing, evaluating and creating activities.

The primary goal consists in introducing an active way of eLearning. Newly developed eLearning modules are based on suitable algorithms representing development of typical projects on data sheets from typical producers and finally on verification (visualisation and simulation where possible). The goal is to approach higher level learning as depicted in Anderson & Kratwohl's taxonomy [5].

4.3 Level 3: Distance experiments

Let's consider experiments in education of traditional physics (giving basic knowledge for all technical subjects). The experiments are used in supporting of lecture demonstrations, high-school classroom demonstrations, and in laboratory. There are two pedagogical techniques used for lecture demonstrations:

1. in a *traditional course*, the students observe an experiment and then the instructor explains *what happened and why*.
2. in a *reformed instruction*, the students predict what is going to happen before coming to the experiment, and then *reconcile their predictions with the observations* that follow.

It is crucial to let students have some real practice. The *real experiment* gives the students a sense of practical testing and they can also see the *influence of the second/higher order effects, real time effects, effects of parasitic* which is difficult or impossible to be simulated perfectly. The reason is that the simulation is always based on a more-or-less simplified model. However, to build an experiment is generally expensive. For an educational institute is impossible to have a complete set of experiments. The solution consists in redesigning hardware experiments so that they also can be accessed by the Web. The proposed *distance experiment* is not any web-based simulation. It is a *real electro-technical experiment* conducted in the laboratory but remotely controlled and monitored by web-based tools.

Here, the experiments can be:

1. either conducted online,
2. or are based on recorded values.

This approach allows students to perform the experiment safely without any guidance. They can also experience the appearance of the measurement instrument, the electronic components and many more factors (e.g. lay-out of the components). In this phase of eLearning development the web technology replaces traditional materials and affects the education programme's organization and execution. Assignments and tests in the electronic learning environment play more important role here. A direct access and adherence to the portal are prerequisite to participate in such courses.

The experiments should be *analysis and synthesis oriented* (i.e. to measure and see the results). They should involve a *design aspect*. Therefore the measurements are designed as a project with leading idea and clear targets.

To design and realise education based on distance experimentation we have to deal with:

- learning objectives for distance experimental education,
- guidelines for project oriented measurements with the learning objectives for distance and /or virtual practical education,
- analysis and synthesis oriented experimental measurements,
- technology and technical documentation for distance practical education and measurements via the Internet,
- different designed measurements each with its own philosophy.
- presented outputs from the project,
- teaching material (in electronic form; guidelines, manuals, documentation chosen languages),
- a web access to distance and virtual experiments,
- visualisation and layout of the measured system,
- measurement results obtained via Internet.

4.3.1 Integrated Learning Platform PEMCWebLab

In our case in field of electrical engineering we have designed a set of distance experiments which cover fundamentals, basic applications of the electrical engineering, and advance topics including the applications, as well (Tab. 2). In the fact, they cover areas of power electronics and motion control. They compose an integrated learning platform, called PEMCWebLab (here *PEMC* stands for the *Power Electronics and Motion Control*).

The main function of *PEMCWebLab* is to provide a web-based remote control for designed experiments. The learning process includes several, specially designed, experimental tasks. However, for safety reasons, no one will be allowed to perform any experiment until he, or she, has shown adequate knowledge of the experiment. Due to insufficient knowledge of the experiment, entering wrong input parameters may also lead to improper operation of the experiment. Therefore, a learning routine is designed for learners to gain the prerequisite knowledge which is required before attempting the experiment.

After completion of the online experiment, the learners have an opportunity

- to take a simple questionnaire, or alternatively
- to submit their report through the available feedback subsystem for its final evaluation (depending on the requirement enforced by the instructor).

Table 2. List of modules with remote controlled experiments in the EDIPE (PEMCWebLab) project

Groups of specialised subjects	Modules
1. Fundamentals of Electrical Engineering	1.1 Single Phase and Three Phase Rectifier Circuits 1.2 DC Circuit Measurements and Resonant AC Circuits
2. Power Electronics	2.3 Power Converters 2.4 Power Factor Correction 2.5 PWM Modulation 2.6 DC-DC Converter for Renewable Energy Sources and Microgrid 2.7 Power Quality and Active Filters 2.8 Power Quality and Electromagnetic Compatibility
3. Electrical Machines	3.1 Basic Electrical Machinery – Synchr.Generator 3.2 DC Machines 3.3 Basic Electrical Machinery – DC Motor 3.4 Basic Electrical Machinery – Induction Motor
4. Electro-Mechanical and Motion Control Systems	4.1 Basic Elements of Internet based Tele-manipulation 4.2 Mechatronics, HIL Simulation 4.3 High Dynamic Drives - Motion Control 4.4 Automotive Electrical Drive 4.5 Complex Control of a Servodrive by a Small Logic Controller 4.6 Intelligent Gate Control by a Small Logic Controller (SLC)

The principal structure of a remote controlled experiment included in a distance laboratory is shown in Fig. 6.

However, the Internet bandwidth becomes extremely limited when too many remote users request to use this system. Several concurrent, remote users are allowed via an Internet connection for each experiment. However, each experiment in the *PEMCWebLab* can be operated only by a single remote user at a time. The system thus considers each experiment as a “resource”, and the remote users wishing to operate a specific experiment should first get a permission to operate it. Once the resource is in use, other remote users cannot access that resource, because it is then marked as “locked.” All the remote users without access permission can see only the online, real-time video of that

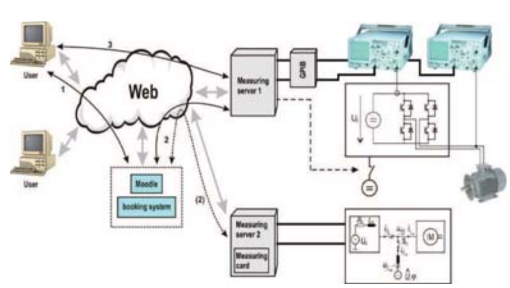


Fig. 6. Principal structure of a distance laboratory

experiment.

Similarly as in level 2, here the modules cover a wide area of *Power Electronics and Motion Control*.

4.3.2 Example of a Remote Experiment

Here, for an illustration only, one module from the 2nd group is analysed in details. In the DelftWebLab (module 2.3), which is a part of PEMCWebLab system, two measurements have been prepared. These are the two basic conversion possibilities, namely DC-DC and DC-AC. Both fit into the integrated learning example of a hybrid car. Only the first application measurements, namely with the DC-DC converter is described here. The DC-DC buck converter was selected (step down chopper) with a resistive load which will later be extended to a DC machine. This converter topology is selected because it forms a basic building block for a voltage source inverter. The objectives of the practical can be summarized by the following points:

- To simulate a typical design process of a converter.
- To show the physical layout and construction of a modern converter.
- To demonstrate the real time effects, delays in the drivers etc.
- To demonstrate the switching effects of power semiconductor switches (e.g. switching on/off and reverse recovery).
- To compare the simulated and measured waveforms.
- To show the influence of the parasitic elements.

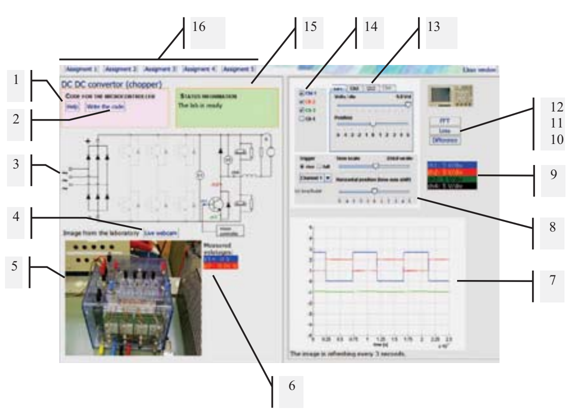


Fig. 7. An example of measurement screen

The assignments are described fully in the ref. [10]. Fig. 7 shows a measurement screen. A short manual presents possibilities of remote experimentation. This manual shows that a remote experiment offers the possibilities which resemble to real practical.

Experiences from the PEMCWebLab show that most of developed distance laboratories are:

1. learning objectives are not defined or not targeted,
2. too difficult to start (large threshold),
3. concentrating on procedural knowledge and programming rather then physical background and understanding,
4. focusing more on conceptual knowledge.

5 CONLCUSION

eLearning has introduced a new access to engineering subjects learning. By implementing interactive animation and simulation it creates an interactive *training environment* that replaces partly the laboratories. However, the danger is that, instead of deep understanding and physical background, the students could memorise the visualised results. These tools therefore cannot perform to stand alone education and they must be part of complete curricula. Most of the interactive tools are focused on "*what-if*" simulations based on moving bars to increase or decrease parameters of the circuits.

In other words: the circuit situations are performed without the use of real values for the circuit's parameters. The sense for real values is hereby very important. eLearning should be based on knowledge of components properties and subsystems behaviour to perform analysis, synthesis and evaluation of the final system and to design the new system based on real (produced) components. eLearning should introduce a possibility of evaluation and judgments about the merits of ideas, verifying value of evidence, recognizing subjectivity. The key words are: *conclude, criticize, decide, defend, determine, evaluate, dispute, judge, justify, compare, rate, recommend, agree, appraise, prioritize, assess, estimate, deduct*. eLearning should introduce an active way towards project oriented learning. Instead of using a short problem as a tool to deliver information and knowledge, a larger scope project should be used. It is well-suited to the engineering disciplines and the way engineers in the industry work.

ACKNOWLEDGMENT

The authors acknowledge the financial support to the project „Interactive and Unified E-Based Education and Training in Electrical Engineering", INETELE, supported by the EU in framework of Leonardo da Vinci II programme and Grant Agency of the Ministry of Education of Slovak Republic under the contract KEGA 103-039TUKE-4/2010 (Students' Skills Development for Mechatronic Systems' Control).

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Received: 2009-12-04
Accepted: 2010-02-11