Modern Teaching and Training in Metallurgical Engineering

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This contribution deals with advanced educational technologies needed to equip customers from higher education institutions, research and industry with efficient tools supporting their work and operating new skills-training methods. The challenges are reducing the training costs, improving quality and increasing the number of graduates in engineering departments. The concept of a Virtual Lab based on the combination of various teaching methods and tools is presented. Principles of mathematisation in metallurgical education and training are discussed. An example of online course designed in the form of Virtual Lab is demonstrated.

Keywords: distance education, e-Learning, virtual laboratory, simulation, interactivity.

Introduction

Nowadays teaching in form of the classic university based on classroom teaching can be extended. New forms should complement it to raise the interest to technical professions and to motivate young talents to study them, to enable flexible study and consequently to increase the number of students in the engineering departments. Study of complex technological processes using mathematical methods, modelling and simulation supported by the newest computer technologies and multimedia techniques for knowledge transfer are of great importance in metallurgical education and training. Up to now, hardly anybody has made full use of the potential of the digital technology and the Internet for a training environment.

A big project “Network of Excellence in Professional Learning (PROLEARN)” funded by the EU Commission has been started 2004 with the mission “to bring together the most important research groups in the area of professional learning, as well as other key organisations and industrial participants, thus bridging the currently existing gap between research and education at universities and similar organisations and training and continuous education that is provided for and within companies” [1]. The challenge for a consortium of 19 European universities and research centres as well as more than 100 associated (mostly industrial) partners is to integrate all European activities in eLearning into a powerful and meaningful community in order to establish Europe as a world leader in this field. One of the activities is related to online laboratories, which are of great importance especially for engineering education. The Department of Ferrous Metallurgy at the RWTH Aachen University participates in the project with the approach and background presented in this paper.

Traditional and new teaching methods

Traditional face-to-face education means that teacher and learner are at the same time at the same place. Distance Education (DE) is the process by which students and teachers can communicate through information technology (e.g. via Internet or satellite connection). It allows courses to take place without the necessity for the students and teachers to physically be at same location [2]. It has to be emphasised that the target of online education in engineering study, at least in the medium term, is to enhance the traditional teaching, not replace it. The characteristic features of the DE tools to be developed should be:

– Replacement of expensive experiments by computer simulation
– Sharing lab equipment between universities by remote access via the Internet
– Exchanging online learning resources and courses between universities and share development expenses.

Virtual Lab concept

Conventional teaching method of complex technological systems often consists of their artificial dissection into separate processes (chemical, physical, mechanical, hydrodynamic etc.) and their consequent description as well as using “if-then” rules.

The concept of a Virtual Laboratory (VL) has been developed at the Department of Ferrous Metallurgy at the RWTH Aachen University. Its main feature is using a traditional teaching method as a component by converting the learning content into digital form using multimedia techniques and complement it by interactive simulation models.

The components of the Generic VL are [3]

– Online book(s) and /or presentation(s)
– Packaged lecture(s)
– Vivid lecture(s)/seminar(s)/live discussions
– Packaged simulations
– Online simulations
– Visual processing lab

Each VL can contain additional components or, on the contrary, reduced number of the components.

Principles of mathematical modelling in metallurgical education and training

Modelling of complex technological processes, phenomena and equipment is one of the important tools not only for process investigation, automation and prediction but also
for educational purposes, in particular for creation of training systems for remote studies.

To realise the VL concept that is based on mathematical modelling and online computer simulations, it is necessary to identify the fundamentals of training of metallurgical engineers and to link, respectively adapt them to the distance learning environment. The first fundamental component is thermodynamics, helping to find out the stable phase modifications in the metallurgical multiphase-multi-component systems of high complexity. This is done by minimising the free energy of formation of those phases, which derives from the principle that in thermodynamic equilibrium the energy of the system is a minimum. The fundamental relation is the expression for the free reaction enthalpy to become a minimum. The principle of conservation of energy provides the basis for formulating energy balances for metallurgical reactions. The second component is chemical kinetics, which allows to calculate the time behaviour of the chemical components due to chemical reactions which take place. The fundamental relation is the mass action law stating that in any chemical reaction the chemical equilibrium is achieved only if the rate of production equals the rate of destruction of species. The rates are usually calculated using Arrhenius kinetics.

By combining these two components the formation and time behaviour of the phases and chemical components existing or created can be monitored and quantified.

Usually movement of the existing phase (liquid, solid, gas) makes necessary the explicit presence and use of the third component, the mechanics. The fundamental relation used to quantify the motion of the system is the principle of conservation of momentum, equivalent to Newton’s second law, in general for fluids as the Navier-Stokes equations.

Combination of the above three components allows to quantify the most essentials of metallurgical problems starting from fundamentals.

A basic principle for adapting the learning content for metallurgical engineering training to DE purposes, e.g. the virtual laboratory concept, is to write down the equations in strict causality relation between the physical and chemical entities and the variables representing them in an agreed causality direction.

The methodological principles for creating and using mathematical models in DE technology are:

- Reduction of number of facts
- Replacing facts by rules
- Replacing rules by laws
- Replacing laws by principles

Methodologically, this is evidently a generic replacement and a generic deduction. Modelling methods are most effective when included in a process plant simulation. Modern simulations allow the user to combine models for several unit operations into a complete flow sheet and to calculate the expected performance. Visual simulation models are particularly beneficial for reflecting the logical and quantitative relationship of complex technological processes and aggregates.

Visualisation of the simulation experiments is the next component for set-up, thus adapting fundamental metallurgical content to DE technology.

**Forms of digital content and multimedia internet applications**

DE can be based on learning material of two different kinds: packaged contents and CSCW (Computer Supported Cooperative Work) supported live contents. Packaged courses are collections of learning material, put together into a single package, which can be retrieved by the content consumer. These systems provide self-study resources in electronic format. Package course files could be hypertext information, slides of a presentation, text files with supplementary information, external references to live or on-demand audio/video content, assessment data, etc.

Any student equipped with an internet connection and a web browser can master theoretical descriptive material available on a web site and carry out computer exercises and experiments.

Web-based teaching materials may provide the opportunity for interactive teaching. Interactivity implies that possibilities are given to affect the presentation form or content. For example, an interactive teaching has been introduced using Matlab/Simulink software[4]. There is a server application that is connected to Matlab as a client; external internet clients access this machine as a server. In this way a deeper understanding can be achieved but the student in the lab only interacts with a computer system. This is so called passive interaction where a teaching system offers “if - then” commands to interact with it.

Active human interaction with a partner can be achieved by CSCW educational activities. CSCW based learning content supports mechanisms, that allow to synchronously collaborate among geographically separated course participants, for example live lectures supported by video conferencing or chat rooms. This enables interactive forms of telelectures combining parallel transmission of audio-visual streams and course material with the possibility to interact with the lecturer as well as with other parts of the audience. Such DE environments also supports real-time experiments, simulations and case studies to enhance learning experience. The trainer is “synchronously” present via remote collaborative tools and the students or the teams can communicate effectively.

Digital content will undergo dramatic change in the next decade [5]. It will evolve to “smart” content that is highly interactive, clustered, predictive, contextual and will enable a visual user experience.

**Example of online teaching and learning of ironmaking**

Web-based course “Ironmaking” has been developed at the Department of Ferrous Metallurgy at the RWTH Aachen University to provide a deep understanding of the complex blast furnace process, related and alternative technologies.
The course includes a set of following logically related components:

**Video lecture** “Ferrous Metallurgy – state of the art and prospects”. The brief, focused lecture gives an overview to the development of the production and use of iron and steel and analyses different ways of steel production. The lecture is delivered as streaming video.

**Online lecture textbook** consists of three main parts that are available in PDF and HTML versions. The first part “Raw Materials and Their Preparation” covers the topics of iron ores and their agglomeration, coals, cokemaking and environment related to the sinter and coke production. Each chapter has a separate list of references. To facilitate and encourage deepening of knowledge on certain subjects this course unit has an extra list of recommended literature in various languages and web resources.

The second part “Blast Furnace Process” covers all important physical and chemical processes that take place in the blast furnace. It takes a closer look at the following three subjects:

- Fundamental processes of blast furnace ironmaking such as reduction and oxidation.
- Technologies which ensure competitiveness of the blast furnace ironmaking like cokemaking, injection technologies and measures for coke saving.
- Topical problems related to sustainable development, environment, waste recycling and energy saving.

The structure of references, recommended literature and links is the same as in the previous unit.

The presentation “Direct and Smelting Reduction Processes” (third part of the textbook) is devoted to the alternative methods of primary metal production. About 50 slides present fundamentals (definition of terms, classification, general analysis of DR processes) and figures for DRI production, characteristics and status for different processes, schemas and brief descriptions for some of them as well as references and WWW resources.

**Compendium** “Blast Furnace Ironmaking”. The target is flexible study of the fundamentals of the iron manufacture. A very brief text gives basic knowledge about blast furnace ironmaking. Step by step learning into the depth from general concepts down to desired level of detail including description of accompanying processes (like cokemaking, sintering, and palletising) is possible by clicking on keywords.

**Processing lab** for investigation of process parameters in the raceway. This zone is a vital region of the furnace that supplies the process with heat and reducing agents. Gas volume and composition as well as adiabatic flame temperature can be calculated directly using this processing lab program. Effect of different parameters (blast temperature, humidity, oxygen concentration as well as consumption and composition of injected reductants) on the above mentioned values can be investigated quantitatively. The exercise is based on a program which is an Microsoft-Windows application that can be downloaded.

**Visual simulation model** “Blast Furnace”. This component is based on a mathematical balance model of the blast furnace process [7-9]. It processes entered parameters and outputs both operating and learning results (figure 1, 2). The model reflects dynamics of the process (delay in the change of output parameters after conducting the control actions). It also simulates the sinter and pellets plant operation as well as work of heat stoves.

The course tutor is equipped with visual software to monitor the activity of the students, answer their questions, and analyse the learning results. Student-tutor and student-student communication is text-based with the use of a message board. The tutor can support students not only by means of this tool but he can also open each student’s session and help the student directly. Students on geographically dispersed sites can collaboratively “charge” and “operate” the same blast furnace and view the results simultaneously. To better analyse students’ work, the tutor can view the computer log of their actions.

![Figure 1. Simplified scheme of visual simulation model “Blast Furnace”](image)
The software “Visual Model” is implemented in Java and therefore able to run on nearly any platform making use of the Remote Method Invocation mechanism for communication via the Internet. The simplified architecture of Visual Simulation Model is shown in figure 3. The framework of the program is kept quite general, so that on the one hand the underlying model or the user interface can be safely changed, and on the other hand models of entirely different processes can be easily added and integrated, given the conformity of the programming interface.

**Interactive assessment tests.** This test consists of 85 questions divided into 10 sessions that cover corresponding chapters, course units and the whole course content. Figure 4 shows a question extracted from an assessment session. The assessment test is also a distributed Java application and runs synchronously at specified times. This software operates in a way similar to the Simulation Model. The course tutor or teacher is provided with visual software to monitor the activity of the students and analyse the learning results.

**Live video conference sessions** are broadcasted via the Internet to support learning activities by live interactive collaboration (figure 5).

**Practice and experience.** The course was held firstly as a two-month Simulation Trial within the scope of an EU IST Project “Universal Exchange for Pan-European Higher Education” [6]. Four European higher education and research institutions took part in the trial. A fifth institution, Swiss university ETH Zürich, participated as a trial evalua-
tor. Altogether, there were 37 participants, including 25 undergraduates and postgraduates, 7 faculty members, and 5 expert reviewers. Student participants who met certain pre-requisites were granted a course certificate. Pedagogical scenarios as well as the assessment procedure and results have been discussed in [10]. The students were generally satisfied with the course having new learning experiences, especially the collaboration with international partners. Simulation visual model “Blast Furnace” has been recognised as the most innovative course component.

Presently the visual model is included in the practical course in the metallurgical education at the Dept. of Ferrous Metallurgy, RWTH Aachen University. Beyond this more than 80 external users have booked separate course units via the EducaNext portal (http://www.educanext.org/ubp) or our web site (http://meveus.iehk.rwth-aachen.de/).

At the moment the visual model “Blast Furnace” is being further developed. Additionally other modules are under development too.

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