

# Virtual Laboratory Concept for Engineering Education

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**ABSTRACT:** *Using mathematical methods, modelling and simulation of complex technological processes and their representation in a comprehensible visual way is of great importance in engineering studies, especially for distance learning purposes. This is, in particular, a unique means of hands-on understanding of the process interrelations, of acquiring practical skills and of learning how to put theoretical knowledge to work in practical engineering situations.*

*The concept of a Virtual Lab is based on the analysis of the cognition process and on the role of mathematical models in the information transfer process. A Virtual Lab for engineering applications should be comprised of a set of logically related components. Online computer simulations and experiments are core components of a Virtual Lab.*

*This contribution deals with structure and design of a Virtual Lab, relations between its components and demonstrates a first example of such a Lab developed for students of metallurgical engineering and material science. The key innovative component of the Virtual Lab is the Visual Simulation Model (VSM) that processes parameters entered and outputs both operating and learning results. The teacher and learners can interact with each other using software interface, which allows monitoring the activity of the learners, answering their questions, and analysing the learning results. The VSM software is implemented in Java, thus being able to run on nearly any platform. The framework of the programme is made quite general, so that the underlying model or the user interface can be safely changed and models of entirely different metallurgical and other engineering processes can be easily added and integrated, given they conform to the programming interface.*

*The Virtual Lab was first offered via the EducaNext portal (<http://www.educanext.org/ubp>) that provides a web-based service for sharing learning resources. The first online Simulation Trial with geographically dispersed students was held in the scope of a EU IST Project. The trial was organised and managed by the Department of Ferrous Metallurgy at the RWTH Aachen University in which the Virtual Lab has been developed. Its performance, evaluation approach and results are reported here.*

## 1. INTRODUCTION

We deal with complex technological processes and aggregates, which cannot be studied integrally either theoretically or experimentally. The conventional teaching method consists of artificial dissection of the process into separate processes (chemical, physical, mechanical, hydrodynamic etc.) and their consequent description as well as using "if-then" rules. Work in a local lab usually deals with experiments that simulate separate parts/zones of a real process/aggregate and sometimes simulate physically phenomena with other materials (e.g., water in place of liquid metal). Construction and operation of physical models that integrally simulate the real aggregates even on a small scale is enormously costly and time consuming, so that it is unrealistic at universities and at the majority of research organisations. Experiments on industrial units are limited for research and are impossible for education and training. Therefore the challenge is not to provide remote access to a laboratory or industrial equipment but virtually to replace equipment that is not available or cannot be used for educational purposes.

## **2. OBJECTIVES AND STRUCTURE OF A VIRTUAL LABORATORY**

The term Virtual Lab (VL) is not defined well yet. E.g. in [1] a Virtual Lab refers to “software simulations of physical devices (e.g. measurement instruments) or other real life systems (e.g. economic systems)”. According to [2], “the main purpose of the virtual laboratory is to permit experimentation ... in a way similar to what occurs in conventional laboratories.” The authors “... hope to reach the same objectives as in a conventional laboratory and even more efficiently in some cases”.

In our understanding a Virtual Lab is based on online computer simulations and experiments but not limited to them. VL is a set of multiple synchronous and asynchronous learning techniques and tools, which are complementary and provide the most efficient mastering of engineering courses by remote study. Asynchronous or packaged material makes learning more flexible and independent from time and place. Synchronous or live material makes learning really interactive. The target is not to get the same results as in a local lab but to open new possibilities, which cannot be achieved without computer simulation due to the problems explained in the Introduction.

The concept of a Virtual Laboratory for technical engineering education has been developed at the RWTH Aachen University, Department of Ferrous Metallurgy [3,4]. Its main feature is using a traditional teaching method (consequent study of separate parts of the technological process or aggregate and using “if-then” rules) as a component by converting the learning content into digital form using multimedia techniques and complement it by interactive simulation models.

To provide profound understanding of a specific discipline or technology, a VL should rely on self-directed, directed and collaborative learning methods, which can be manifested in the following educational activities:

### (a) Directed Learning

- Introductory videoconferencing session
- Demonstration of the computer simulations by videoconferencing or synchronous VL mode
- Video of the recorded or live materials, giving an overview on the subject of a course and show its place and role in the chain of related processes or technologies

### (b) Self-directed Learning

- Individual learning of online, packaged educational material, enhanced by asynchronous remote tutoring in the form of email exchange
- Individual interactive assessment tests on the material mentioned above, enhanced by real-time online remote tutoring
- Individual work in an asynchronous processing lab
- Individual work with real-time computer simulations, supplemented by an interactive assessment test and enhanced by real-time online remote tutoring

### (c) Synchronous Group Collaborative Learning

- Collaborative work with computer simulation models, supplemented by interactive assessment tests and enhanced by real-time online remote tutoring
- Live discussion of results and assessment using a videoconference or other communication means.

## **3. ROLE OF MATHEMATICAL MODELLING AND SIMULATION IN EDUCATION AND DISTANCE LEARNING**

Modelling of complex technological processes, phenomena and equipment is one of the important tools for process

- Investigation for its better understanding and further improvement
- Control and optimisation
- Prediction

as well as for educational purposes, in particular for the creation of training systems for remote studies.

To realise the VL concept presented in the previous chapters, it is necessary to clarify the fundamentals of training in different engineering professions and to link respectively adapt them to the distance learning (DL) environment. The fundamental components of a majority of technological systems such as those in the chemical, metallurgical, fuel and energy branches etc. are thermodynamics, chemical kinetics and mechanics. A combination of the above three components allows to quantify the most essential technological problems and situations.

A basic principle for adapting the learning content for technical engineering education to DL 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 DL technology are:

- Reducing the 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 DL technology.

## **4. EXAMPLE OF VIRTUAL LAB “IRONMAKING”**

### **4.1. Outline and characteristic features of the blast furnace process**

Ironmaking studies the processes and technology of the iron production. About 95% of primary metal is made by a blast furnace process that is a continuously operating shaft furnace based on the counter flow principle.

The blast furnace process is a good example of a complex multi-phase and multi-component technological process. It is characterised by numerous phenomena (physical, chemical, physico-chemical, mechanical and hydraulic) and homo- and heterogeneous reactions, which occur simultaneously and affect each other. The peculiarities of the blast furnace process as a modelling object are:

- Interconditionality; every output variable depends on a multitude of input variables;
- Non-linearity of relations;
- Inertia and transport delay;
- Ambiguity and losses of information: it is possible to generate two different sets of inputs which are adequate to the given set of outputs.

### **4.2. Components of the Virtual Lab**

Web-based VL "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 as well as the role of iron making in the steel industry

using self-directed, directed and collaborative learning methods [3,5]. The VL consists of multiple asynchronous and synchronous components. It reflects the concept of a VL presented in the previous chapters but realised now to a certain extent.

It includes a set of the following logically related components:

- (1) A brief focused streaming video lecture giving an overview of the development of the production and use of iron and steel analysing different ways of the steel production.
- (2) Online lecture textbooks available in PDF and HTML versions.
- (3) A leaning unit “Blast Furnace Ironmaking” that enables the flexible study of the fundamentals of the iron manufacture and provides with quick access to information when working with a simulation model.
- (4) A processing lab for the investigation of process parameters in specific blast furnace zones. It is based on a MS-Windows programme.
- (5) A visual simulation model “Blast Furnace” (will be described in the next section).
- (6) An interactive assessment test is a distributed Java application running synchronously at specified times. This software operates in a similar way as the Simulation Model. Figure 1 shows some questions of an assessment session. The tutor is provided with visual front-end software to monitor the activity of the students and analyse the learning results.
- (7) Live videoconference sessions broadcasting via the Internet to support learning activities by interactive collaboration.

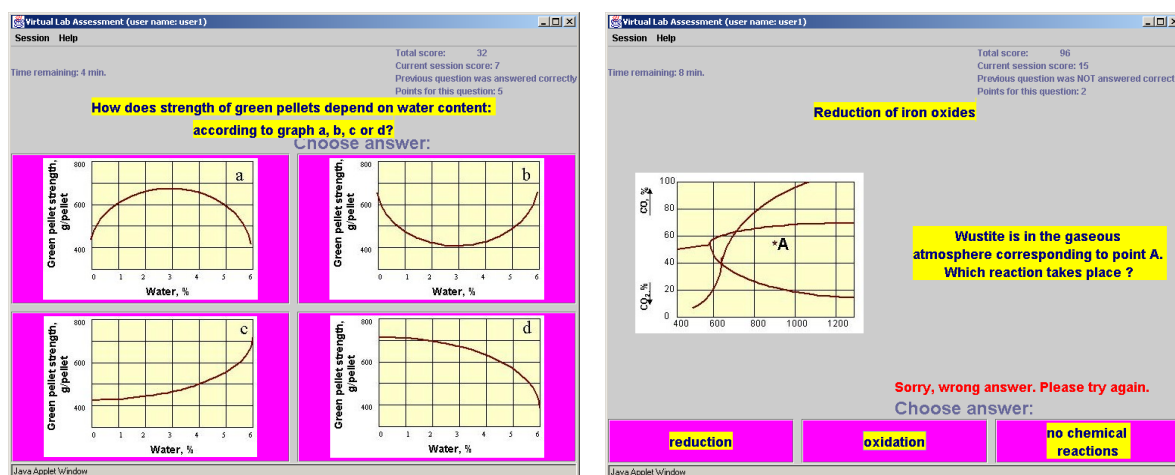


Figure 1 – Excerpt from an interactive assessment test

### 4.3. Distributed Simulation Model of the Blast Furnace Process

The most intriguing part of the VL is the interactive, distributed application “Visual Simulation Model” (VSM) that helps to train and test learning success of the students (Figure 2). The aim of the simulation is to transform the existing knowledge about the iron-making process using mathematical models for DL purposes and to represent this complex technological process visually and dynamically.

The simulation model processes inputted values for parameters to generate operating and learning results (Figures 3, 4). The operations of the simulation model are progressively difficult. In the first step values of individual parameters and the list of mandatory parameters are checked. In the second step the combination of individual parameters is verified. In the third step total material and energy flows are examined and corresponding recommendations are given if necessary. The next part of the work using the VSM is the Process Control. It means that obtained operating results can be improved. Various modes to achieve this goal are foreseen: change of parameters in the main menu and choice of correcting actions suggested by the model. Before making the decision about

control actions, a student has the possibility to forecast change in value of some output parameters using an add-on calculation program (Figure 5). Whenever errors are committed (i.e., wrong or missing values for parameters), penalty points would be incurred and accumulated to the final grade.

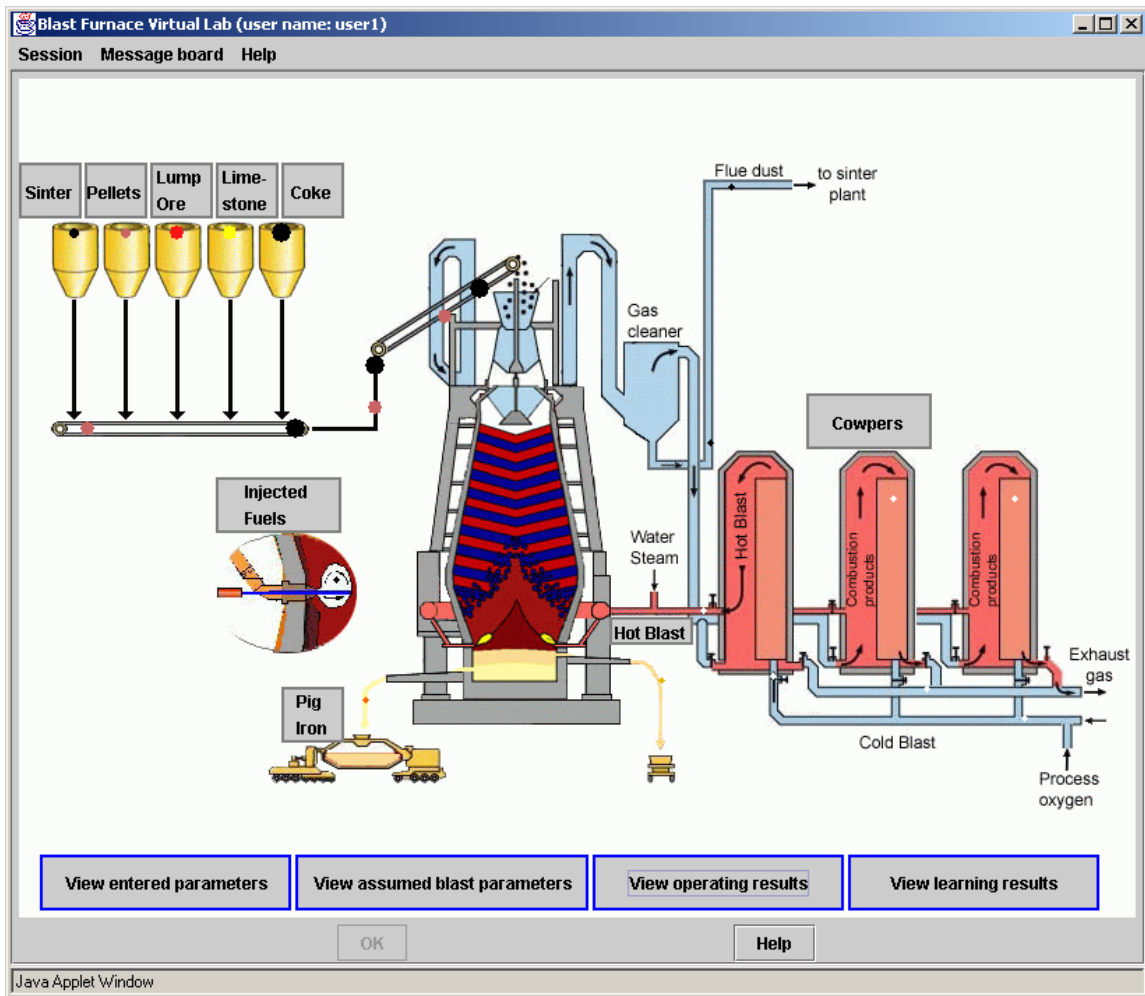


Figure 2 - Screen shot of the VSM user interface

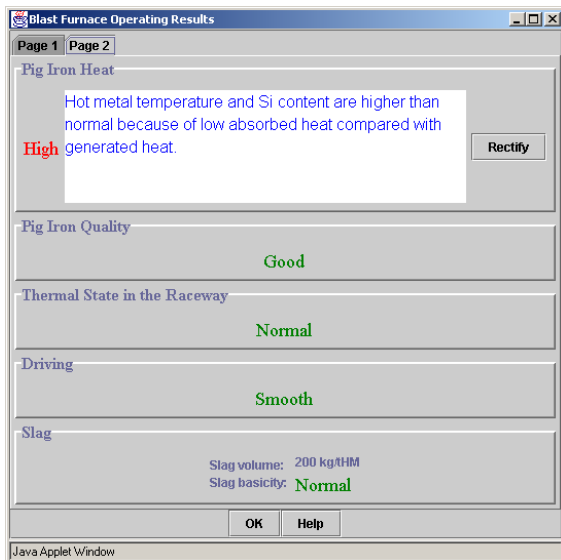


Figure 3 - Operating results

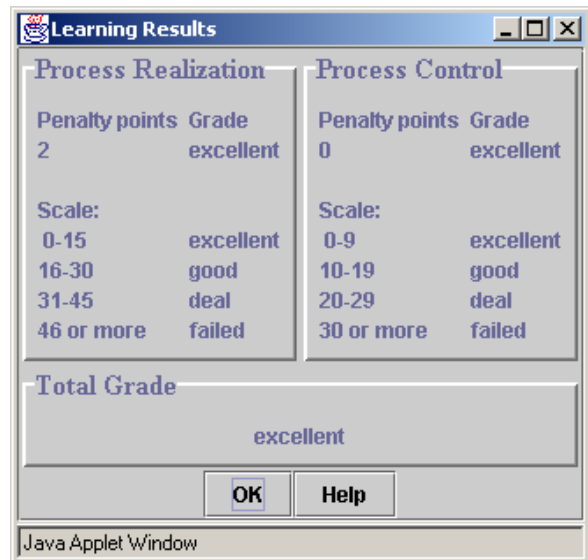


Figure 4 – Learning results

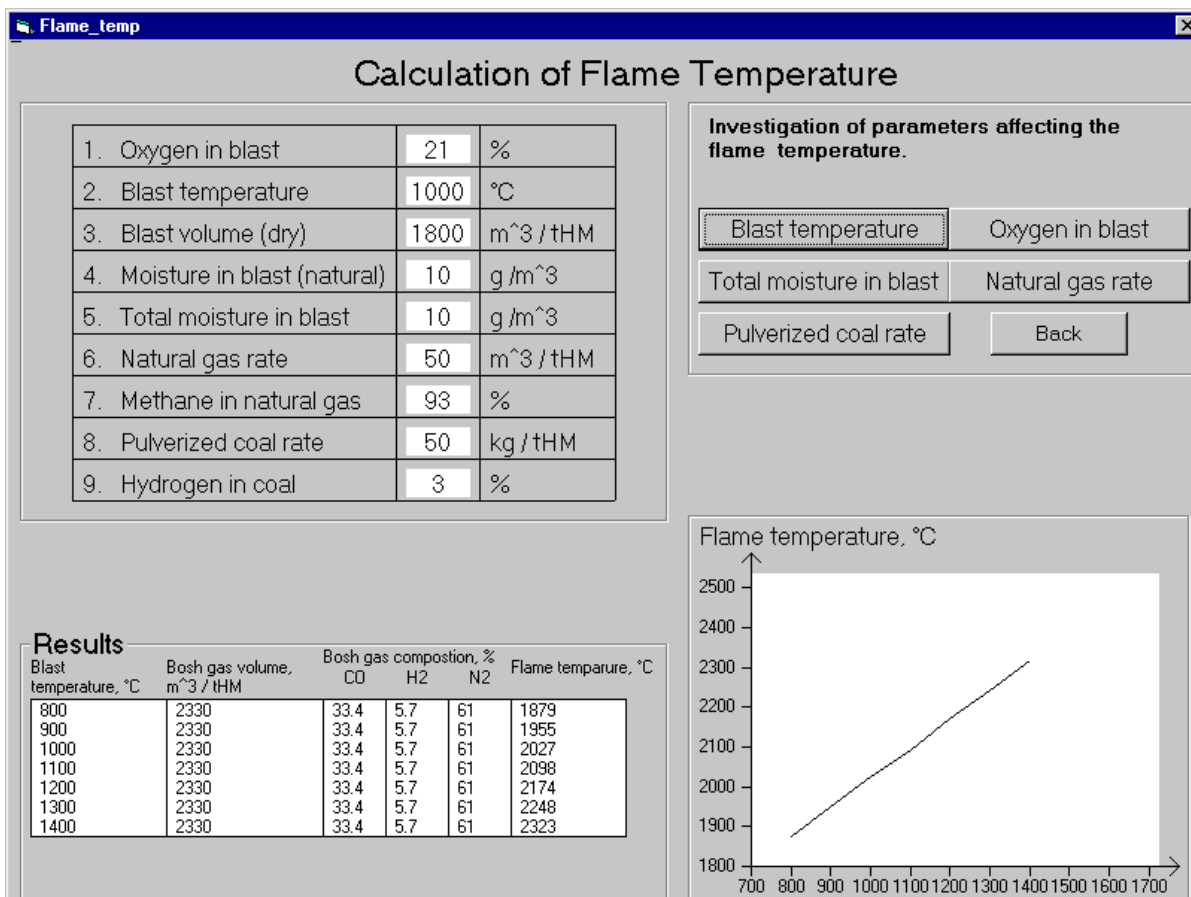


Figure 5 - Screenshot of an add-on calculation program

The remote tutor is equipped with visual front-end software to monitor the activity of the students, answer their questions, and analyse the learning results. Student-tutor and student-student communications are text-based with the use of a message board. Students on geographically dispersed sites can collaboratively ‘charge’ and ‘operate’ the same simulation model and view the results simultaneously. To better analyse students’ work, the tutor can view the computer log of their actions. The VSM software 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 and communication stack of VSM is shown in Figure 6. The framework of the programme 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.

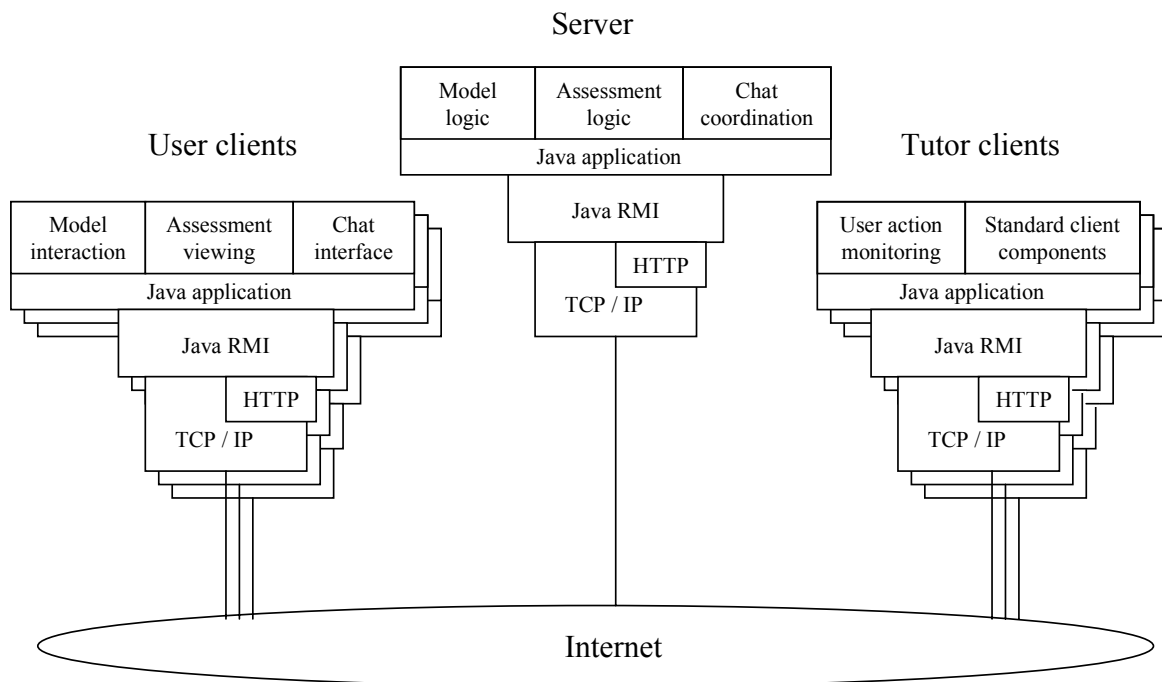


Figure 6 - Simplified architecture of VSM

#### 4.4. Simulation trial and evaluation

The VL was tested firstly within the scope of a EU IST Project “Universal Exchange for Pan-European Higher Education” [6]. Four higher education and research institutions took part in the trial. Two of them are located in Spain, one in Poland, and one in Germany. A Swiss university participated as a passive site and trial evaluator. This CSCL project involved a multi-national team working in orchestration with each partner assuming specific tasks. The “Course Provider” played the central role in designing the learning resource and in coordinating the participation of different sites. “Trial Evaluator” served as a peer reviewer, meta-assessing the trial as a whole. Altogether, there were 37 participants, including 25 undergraduates and postgraduates, 7 faculty members, and 5 expert reviewers. Student participants who met certain prerequisites were granted a course certificate, which served as one of the incentives for their participation in the trial.

The trial evaluation was divided into of three phases [7]. First, the learning system had to undergo several rounds of pre-trial tests, including usability tests of the user interface as well as the network connectivity tests of the server. The next two phases were in-trial (formative) and post-trial (summative) evaluation. Statistical analysis of post-trial evaluation based on 5-point scale rating (1 = terrible ... 5 = excellent) is shown in Table 1.

Table 1. Summative evaluation of all VL components

Content	Presentation	Interactivity	Support	Overall Satisfaction
4.42	4.03	3.77	3.65	4.25

The evaluation results showed that the students were generally satisfied with the course having new learning experiences, especially the collaboration with international partners. In particular, the high acceptance of the VSM confirmed the assumption that visualizing of complex concepts can greatly enhance the students’ motivation to learn. However, the rather unstable and slow network connectivity, which could be attributed to the bottleneck link between Poland and GÉANT, undermined the quality of video communication between the remote tutor and students and the students among themselves.

## CONCLUSIONS

A concept and a structure of a Virtual Laboratory for technical engineering education that relies on self-directed, directed and collaborative learning methods has been developed.

Web-based VL "Ironmaking" based on this concept, including a set of multiple logically related asynchronous and synchronous components has been built. An interactive, distributed application "Visual Simulation Model" is a key innovative component of the VL that helps to train and test the learning success of the students.

The VL was successfully tested with four European institutions. The evaluation consisted of three phases and was conducted by an independent evaluator from a Swiss university.

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