

# An Interdisciplinary Virtual Laboratory on Nanoscience

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## Abstract

The Swiss Virtual Campus project "Virtual Nanoscience Laboratory" realises a virtual laboratory for the booming field of Nanoscience. Nanoscience laboratories are expensive and only major companies and organizations sponsored by research programmes can afford their usage. With a concept of distance education, complex and sensible experimental equipment can be shared through the Internet.

Three main topics are realized in the framework of a virtual laboratory: user management, communication and co-operation, and the control of virtual experiments. The basic architecture is based on a multitiered client-server model. Each nanoscience experiment is implemented as a stand-alone web-service.

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## 1 Introduction

Through the exponential growth of interconnected computers and a proliferation of services (e.g., e-commerce), the Internet has become an everyday working tool. The presence of the Internet and related information technologies also has a major impact on the field of teaching and learning. Research projects have already explored different directions of technology-supported education [1,2,3,4,5], which has resulted in prototype systems and related experiences. Especially distance-learning has been explored for quite some time. The development of new and more powerful software and information technologies (e.g., Java and XML), as well as the increase of wide-area network bandwidth, offers a new generation of learning facilities and tools. The effective integration of these information technologies and new learning strategies is still a major challenge, and many countries and organizations have started co-ordinated research and development programmes. Switzerland has initiated several programmes with the emphasis on new learning technologies [6,7,8]. In this paper we report the present state of the project "NanoWorld", one

out of 27 projects of the federal program Swiss Virtual Campus (SVC). SVC targets for innovative teaching support in various fields and puts emphasis on the integration of new e-learning modules within the standard curriculum at various universities.

The application area of "NanoWorld" is nanoscience, a booming field with forthcoming applications in many science branches. G. Binnig and H. Rohrer from the IBM research laboratory in Rüschlikon were awarded with the nobel prize in 1986 for the invention of the scanning tunneling microscope [9], the first tool which handled structures at the atomic scale. In the following decade, an enormous number of different applications on the nanometer scale have been introduced. The scanning probe microscope is the nucleation tool for a new branch of interdisciplinary research in biology, pharmacy, chemistry, and physics. As a result, important industry departments shift from the field of microscopic research to the field of nanoscience. The perspectives of nanotechnology are definitely promising, since nanotechnology enables increased integration, better functionality at lower costs, and improved adjustment to future functionality.

Nanoscience student laboratories do exist and are the basis for ongoing research and teaching. The present state is however insufficient for several reasons:

- Nanoscience laboratories are expensive and only major companies and organizations sponsored by research programmes can afford their usage. Neither SMEs nor colleges or high schools have access to this new technology, which hinders their breakthrough.
- The high financial investment also puts priorities on the research part. Teaching nanoscience by using real-world equipment is rarely done and curricula still require renovation.
- There is a third and even more striking problem with real-world laboratories. These environments are complex and the initial amount of time needed for learning the infrastructure is prohibitive.

The goal of the project "NanoWorld" is to overcome these obstacles by realizing a "Virtual Nanoscience Laboratory". "Virtual Laboratory" is a term used in literature for two distinct purposes:

**Simulation of laboratory infrastructure:** Simulated environments target for low-cost, user-driven experiments. Examples are public domain applet collections [10], as well as commercial packages offering high-quality multimedia support [11].

**Remote control and observation of real-world equipment:** Remote control targets for site independence[12,13]. The standard mode is a web integration of cameras together with interfaces to real equipment [14,15].

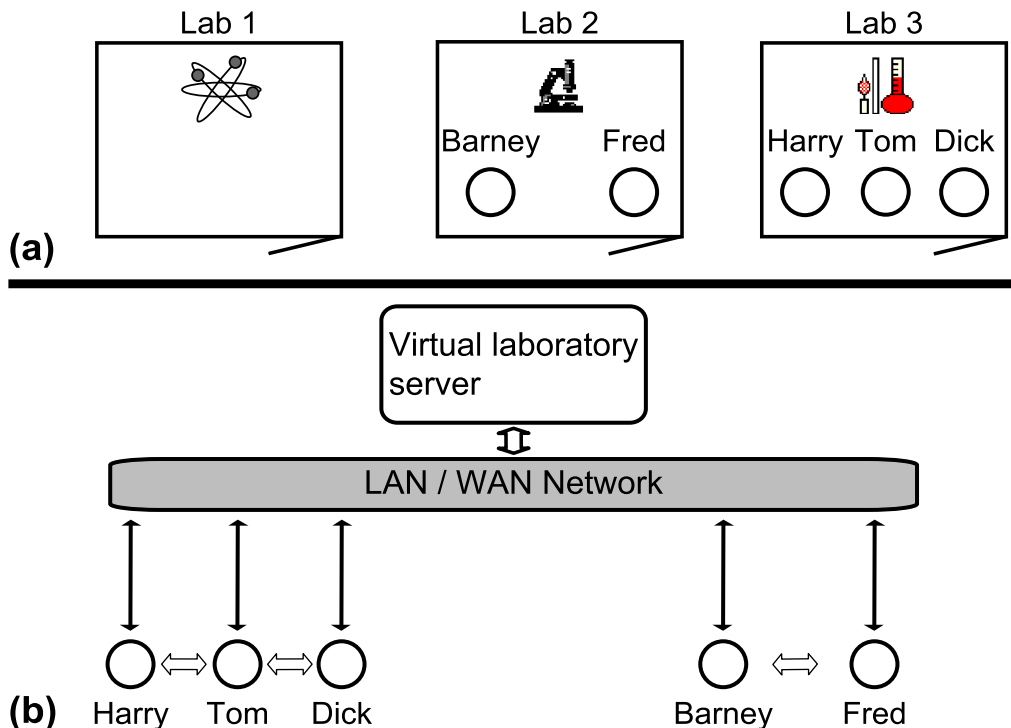


Fig. 1. (a) metaphor of a virtual laboratory; (b) technical realization

”NanoWorld” will integrate both directions. Simulated experiments should give an insight into the methods of the different branches of nanoscience. The experiments will be presented within a co-operative learning environment. A further goal is, to support a smooth change of user interactions from a simulated mode towards remote control of real hardware.

The outline of this paper is as follows: Section 2 describes the basic architecture of a virtual laboratory targeting for both directions. Section 3 describes the implementation of the prototype system and a first experiment. Section 4 gives a summary of the current state and planned project activities.

## 2 Functionality and architecture of a virtual laboratory

A standard laboratory in the real world has a certain functionality. Registered students can enter and leave the lab and a security door protects the laboratory against unauthorized access. Inside the laboratory, communication between the students enables interchange of their knowledge. The group can adapt new strategies to perform the experiment in a better way and discuss the obtained results. A change of an experimental parameter and the reaction of the experiment can be directly observed. This functionality can be divided into three main topics: (1) user management (2) communication and

co-operation tools (3) control of the experiments. Thus, the implementation of a virtual laboratory has to offer all three functionality topics. fig1 (a) introduces the metaphor of a virtual laboratory. It is divided into several rooms with experiments. Students can enter these rooms and work together on experiments. In the technical realization fig1 (b), users are connected via the Internet to the virtual laboratory server where different services for the experiments are running. The core computation is kept on the server side. A small client application presents a laboratory view and allows an interaction with other students or tutors by means of the server side application.

### *2.1 User management*

Different groups of users, such as administrators, course managers, tutors, and students have access to the same virtual laboratory. Administrators manage and implement virtual experiments, course managers organize labcourses for students, tutors support the students fulfilling their experiments. Additionally, tutors observe the status of performed experiments. The students, organized in small learning-groups, perform experiments in the laboratory cooperatively. The detailed user information is stored in a user database which is also used for authentication on different services (e.g. experiments or administration tools). User access control protects the laboratory from unauthorized persons.

### *2.2 Communication and co-operation tools*

In a virtual laboratory, a small group of students explores and investigates a variety of objects and material co-operatively. The students are able to discuss problems and possible solutions by communicating via an integral audio, video or chat channel. The measured data is analyzed by the whole group together. A few of technical equipments for different analysis are systematically installed. Any user manipulations are simultaneously reported to the co-workers.

### *2.3 Control of the experiments*

In a virtual laboratory, where experiments from recent research are simulated, all known features, physical parameters and abnormal behaviour of the real instrument have to be integrated. A hierarchy of user interfaces (UI) is preferably offered: "A Beginners mode" reduces everything to the bare minimum but nevertheless provides first insights. "An Expert mode" will provide a view identical to the UI of the real instrument. In between, one or several types of "Intermediate mode" will bridge and accompany the student during different

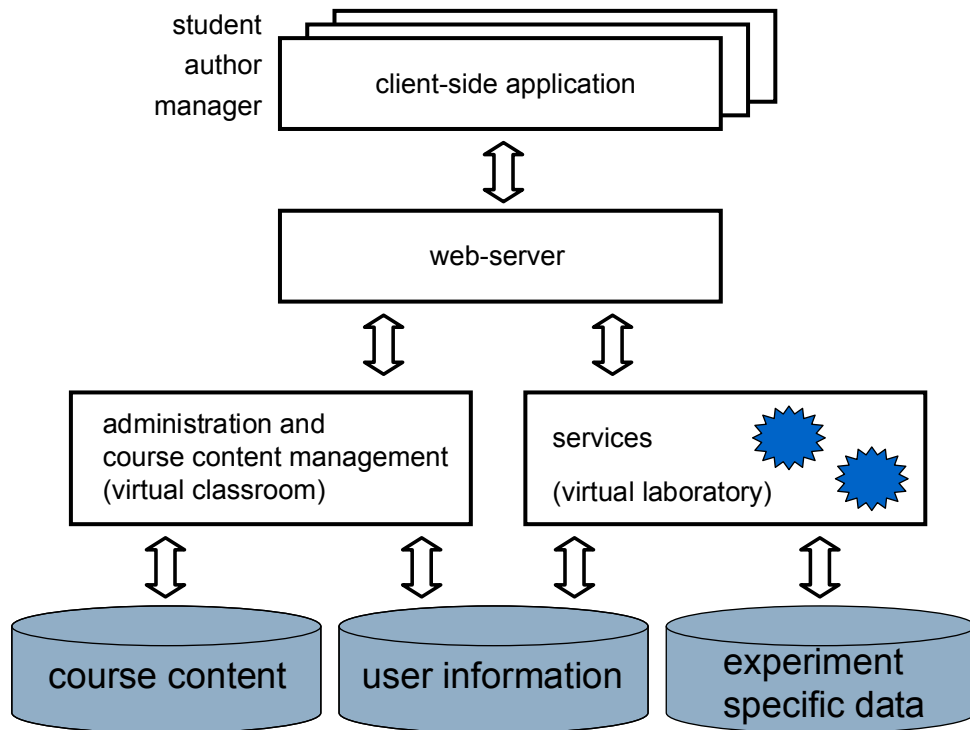


Fig. 2. High level view of the virtual laboratory architecture. Students, authors and managers, working in the virtual laboratory use a web-based interface. A web-server distributes the requests among a static content, administrative block and interactive services of the virtual laboratory. Course content, user and experimental specific data are stored in separated databases symbolized by cylinders.

phases of the course. The same strategy will hold for the tasks to be solved. While first experiments put emphasis on idealized conditions, later steps will target for realistic situations.

#### 2.4 Basic architecture

The basic architecture of a virtual laboratory is a client-server system as presented in fig2. The server side consists of two subsystems (virtual class room and core virtual laboratory) which share three types of data repositories (course content, user information, and experiment data). A user has access to the virtual laboratory via a standard browser. Every user has at least three different bindings: (1) Courseware author setting up the content repository (2) Lab administrator setting up and maintaining the user and group profiles (3) Lab user (student) executing experiments.

The interactive part of the laboratory, e.g. the experiments, consists of simulation and interface services. Pluggable software components (e.g., servlets) from component libraries require a flexible and framework-oriented system

structure. The course information and the user administration (rights, marks, etc.) are part of the content management system which control the access to the underlying database. Main requirements for the content system are (1) multi-lingual support (2) support of multiple, concurrent authors with different access levels and version control. Additional services (e.g. search, collaborative filtering, recommendation services) can be modularly implemented in the content management system. In the user database, the privilege and progress of the users need to be tracked and saved. The experiment specific data is stored in an additional experiment database.

### 3 Virtual experiment framework

The implementation of a nanoscience experiment involves a complex set of information about the underlying physics, technical systems and relationships among the users. In this section, we outline a framework [16] based on an object-oriented model for interactive physics experiments with control and communication channels. The framework uses "state of the art" software engineering concepts by a set of reusable components designed for development of virtual experiments. The features of this framework have been designed for the following tasks:

- (1) Objects are inherently reusable, and are readily amenable to be used for several types of experiments.
- (2) Cooperative use of the experiments
- (3) Support for launching, monitoring and steering the experiments
- (4) Customization and scripting through the use of a fully extensible interpreted command language

The view of the virtual experiment architecture is shown in fig3. It depicts the relationship between the main components of the framework, which is subdivided into an physical layer and a communication layer. The control of the experiment is located in the physical layer, where the simulator component represents the operation of the experiment. The simulator control component encapsulates the overall management of the simulator.

The communication and co-operation tools are located in the second layer, where the command parser component manages the controller request from the different users and verifies the access through the user database. The communication between client and the information layer is performed through a fully extensible command language. The data fork delivers all connected clients with the experiment data stream from the simulator. It organizes the user connections and opens communication channels between the users.

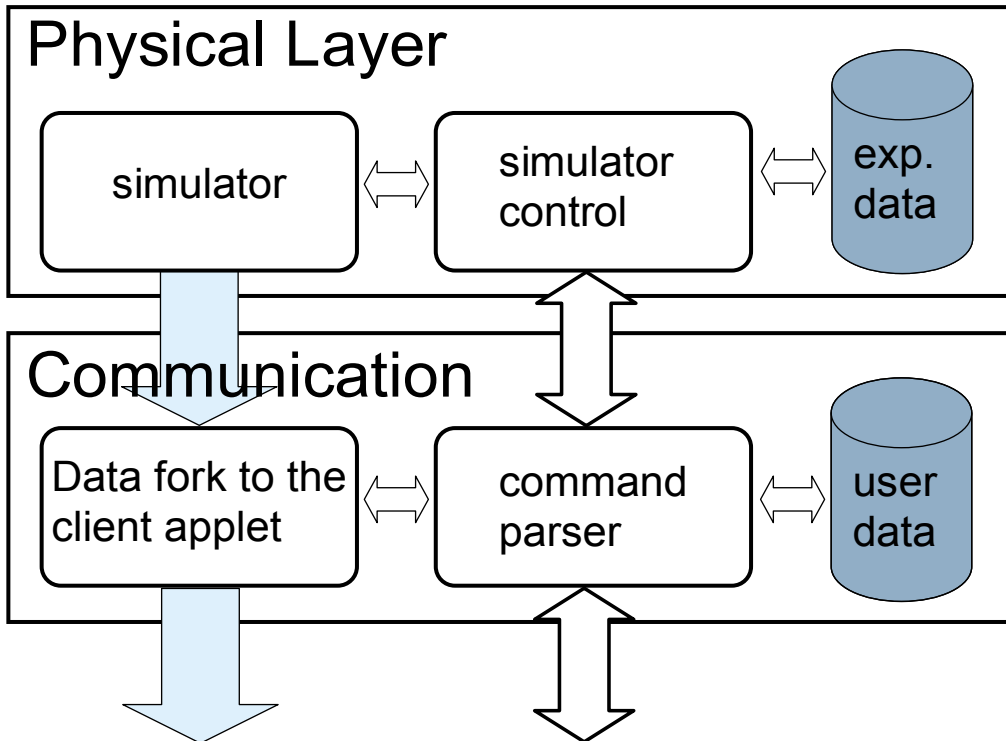


Fig. 3. Framework of an experiment service. The physical layer controls the experimental part, the second layer organizes the communication. The components communicate with each other via JAVA events. The data fork distribute the output of the stream to all students which cooperate within the experiment

For a better understanding of the interactions between the components, a possible scenario is presented as follows: A student called Barney sits in a room of the laboratory and is performing an experiment (e.g. scanning probe or raster eltro microscope). Another student Fred knocks on the door, enters the lab and collaborates the running experiment. In a next step, Fred wants to change a parameter of the experiment (e. g. the zooming gain). The technical view of this scenario consists of two elements:

**Fred logs on to the experiment:** The client sends a request to the communication layer. Fred is authenticated as a student. The request is parsed and interpreted from the command parser. Barney is notified of Fred joining the experiment. An event is sent to the data fork component which delivers Fred with an additional output stream of the experiment.

**Fred changes a parameter of the experiment:** A request is sent from client Fred. After authentication, the command is parsed. The command interpreter verifies Fred's privileges and forwards the command to the simulator control. The command interpreter notifies all users of the experiment about the change of this parameter. The simulator control tracks the change of status in the experimental database and changes the parameter of the simulator component. A variety of other scenarios can be performed within this

framework.

## 4 Current state and future work

Project Nanoworld started on July 2000. So far we have designed the overall architecture of the system described above and evaluated basic technologies which are based on opensource software for completely platform independence. JAVA technology is used for the implementation of the interactive parts. A friction force microscope will be the first implemented experiment. The parser is running under development conditions. The Zope content management framework [17] is used for student administration and course content. Current information of the project "NanoWorld" is available under: <http://www.nanoworld.unibas.ch>.

Several upcoming aspects had to pay regard to:

- (1) Security, performance and scalability of the framework
- (2) Improvement of virtual communication, audio and video channels
- (3) Course management interface to facilitate the work of the authors.
- (4) General authentication interface
- (5) Smart agents which react on experimental problem and support the students interactively.
- (6) Motivation on psychological level with team competitions and remote experiments

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