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Collaborative Nanoscience Laboratory with Integrated Learning Modules

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Abstract: Creation and maintenance of virtual laboratories needs an interdisciplinary project team with didactic and technical staff and also experts of the field. NANO-WORLD, a collaborative nanoscience laboratory, developed as part of the Swiss Virtual Campus, is built on top of an e-learning portal. Interactive real-time simulations of nanoscience experiments inspire students to access e-learning modules. Remote experiments with mobile notification services increase the learning motivation of students. They can directly explore phenomena in nanoscience and take over the role of scientists.

Keywords: Collaborative webservices · Content management systems · Distance learning · e-Science · Nanoscience grid · Remote experiments · Virtual laboratory

1. Introduction

Nanoscience has passed a booming decade with a large number of newly built nanoscience laboratories and centers of competence all over the world. However the present state of nanoscience education is insufficient for several reasons:

- Nanoscience laboratories are still expensive and only major companies and organizations sponsored by research programs can afford to install and maintain such a facility. In general neither small- and medium-sized companies (SMEs), medium-sized colleges or universities, nor schools have access to this new technology, which hinders its breakthrough.
- The high financial investment forces priorities to be placed on research. Teaching nanoscience by using real-world equipment is rarely done and present science curricula still require renovation. Only a few universities – among those the University of Basel – offer degrees in nanoscience.
- There is a third and even more striking problem with real-world laboratories. These environments are complex and the initial amount of time needed to learn to handle the infrastructure is prohibitive.

The goal of the project NANO-WORLD is to overcome these obstacles by *realizing* a 'Virtual Nanoscience Laboratory'. NANO-WORLD integrates simulated experiments, and remote-controlled access to real experiments into an e-learning platform [1][2].

This paper is organized in three parts. The first part describes the content management system (CMS) which manages all e-learning components in a central repository (*e.g.* java programs for interactive simulations, multimedia content, scientific movies, …). The second part explains the virtual experiment framework developed and a first implementation of a nanofriction module. The third part describes the integration of a remote-control microscope.

2. Content Management Support for e-Learning Modules

An e-learning portal offers students, tutors and authors cooperative, worldwide access to interactive learning material. To be successful it has to support a basic set of features:

Core Functionality. Middleware software which opens a central repository to be accessed over the Internet includes security, organization, maintenance, and backup tools. According to this, the e-learning portal has to support a roll back mechanism for each operation on the database, an access security model and replication of the whole repository. An internal fulltext search engine eases fast search operations for specific topics.

Different Content Management Interfaces. A web interface allows *in situ* changes of a specific e-learning content. Larger revisions can be made on local computers. After testing and verification, the new version of an e-learning module can be uploaded and synchronized with the repository.

Multi-authoring. Multi-authoring has to be supported in a way that different authors can co-operatively work on an e-learning module. This requires shared data spaces, workflow procedures, communication and synchronization support.

Extensibility. An open API structure allows an extension of the platform. Addi-

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tional access to the source code guarantees integration with other services in the LAN.

Internationalization Support. e-Learning portals targeting for a worldwide audience have to support internationalization.

Scalability and maintenance are two central issues for e-learning portals which can be addressed by well-structured and modularized content. Separation of layout and content guarantees a unique look and feel which can be globally defined by the designer team, whereas the authors do not have to be concerned about the layout and format of the output page.

An evaluation of e-learning portals and content management tools created in 2002 did not identify a suitable platform. Most of the products were too strict and did not allow an integration of our own interactive Java™ modules. Candidates only barely supported XML or custom-designed content models. Most of them supported only simple form-based interactions with students and use embedded email communication.

Due to the limits of available commercial and open source frameworks for e-learning portals, we have chosen to configure our own e-learning platform on top of the open source content management system (CMS) Zope [3]. The chosen generic CMS system follows object-oriented principles. All objects are stored in a tree-structured DB and can be directly addressed *via* URL with individual access and security restrictions. It is possible to perform a roll back of every applied transaction on the DB. Zope provides the core functionality for web-based portals and specially for e-learning portals.

An API allows the configuration of different adaptors to the repository to configure user-specific and problem-specific interfaces. Multi-authoring is provided through the internal repository with version-tracking from the CMS.

The setup of the repository is designed in such a way that a mixture of layout and content is forbidden. This allows in a later project phase a complete redesign of the web interface. It is also possible to support other devices than pure HTML browsers. Internationalization support is provided for German and English in this phase (2000). An extension to other languages can be easily initiated by any project partner. The translated plain text documents have to be integrated in the content tree of the repository. This can be done directly *via* a web interface or on a local computer.

Specific e-learning functionalities can be implemented over the API of the CMS. The learning-map functionality improves the orientation in the learning modules and helps the students to structure knowledge. A learning map provides visual orientation about the learning content and allows the student to track his learning progress [4]. It shows a network similar to a tree structure with one main and several side branches. All links between the different learning goals are dynamically system generated. A change in the content structure implicitly reorganizes the paths in the learning map without any additional configuration.

3. Virtual Experiment Frameworks

Current e-learning modules must contain a certain level of interactivity to inspire students. Added value, *e.g.* direct synchronization, and improvements of the learning process can attract students to access learning modules. With virtual experiments [5] [6] students can investigate behaviors of complex processes which are hidden or difficult to observe in real-world observations. They can take over the role of a scientist and explore fundamental laws in the field of nanoscience. Results and phenomena can be observed and discussed to find explanations or models. During this active learning process, students can build virtual collaborations – so-called learning-groups – with other students, experts or tutors who are working on the same experiment. Every member in a learning group can observe instantaneously the activities of other students. On demand, a tutor can enter into the learning session and assist the group.

The interoperability of the virtual experiments is realized by so-called webservice and grid technologies. Our framework uses 'state of the art' software engineering concepts by using a set of reusable components designed for development of virtual experiments. Features of the framework designed include:

a) Objects are inherently reusable, and are readily amenable to be used for several types of experiments
b) Co-operative use of the experiments
c) Support for launching, monitoring, and steering of experiments
d) Customization and scripting through the use of a fully extensible interpreted command language

The detailed architecture of the virtual experiment framework is described elsewhere [7].

3.1. *Friction on the Atomic Scale (Fig. 1)*

Friction is a very old phenomenon and plays an important role in global economics.

However, until 1980 friction was considered as 'dirty physics'. After the invention of the scanning tunneling microscope [8] was honored with the Nobel Prize in Physics (Stockholm 1986) Binnig, Quate, and Gerber developed a generalized scanning probe microscope (SPM) [9]. SPM is nowadays the enabling technology of most branches and fields in nanoscience. The invention of scanning probe microscopy also had a deep impact on the research of friction. It was possible to perform friction experiments under well-defined conditions. Since the poorly known environment conditions were the main problem of friction physics, a new age in this field began when it became possible to study forces on a local scale [10][11].

The friction simulator is the first implementation of a cooperative experiment according to the virtual experiment framework. Friction measurements can be performed on an atomic flat NaCl surface with no difference to measurements with a real SPM. Students can observe the atomic scale stick slip [12][13] in the same way as the scientists who first observed this phenomena in the early nineties.

The complexity of a real SPM is rather high and these instruments are expensive and very few of them are usually accessible to students. The friction simulator allows students to directly explore phenomena in nanoscience without the extremely sensitive handling of a real SPM. The use of simulators for training enjoys good acceptance with students and has a high learning effect because it lets the students learn by doing.

3.2. *Cooperative Visualization Toolbox (Fig. 2)*

All nanoscience experiments (real or virtual) produce digital data. This data is normally visualized by proprietary blackbox software delivered with the instrument. The fundamental purpose of any visualization is to communicate information to users. In particular visualization of nanoscience measurements provides an intuitive and efficient means for the exploration and analysis of complex structures in a nanoscopic world [14][15], which is otherwise hardly imaginable. The nanotoolbox provides a set of high-level customizable components for visualization and analysis of specific nanoscience data. Experts can easily add new components to the toolbox which addresses additional particular tasks in nanoscience or in related fields of visualization.

Users of the toolbox can put their archived or real-time data from simulations, remote experiments (Internet) or self-measured experiments into the toolbox. A number of different filters or analysis tools can be used to analyze the nanoscience

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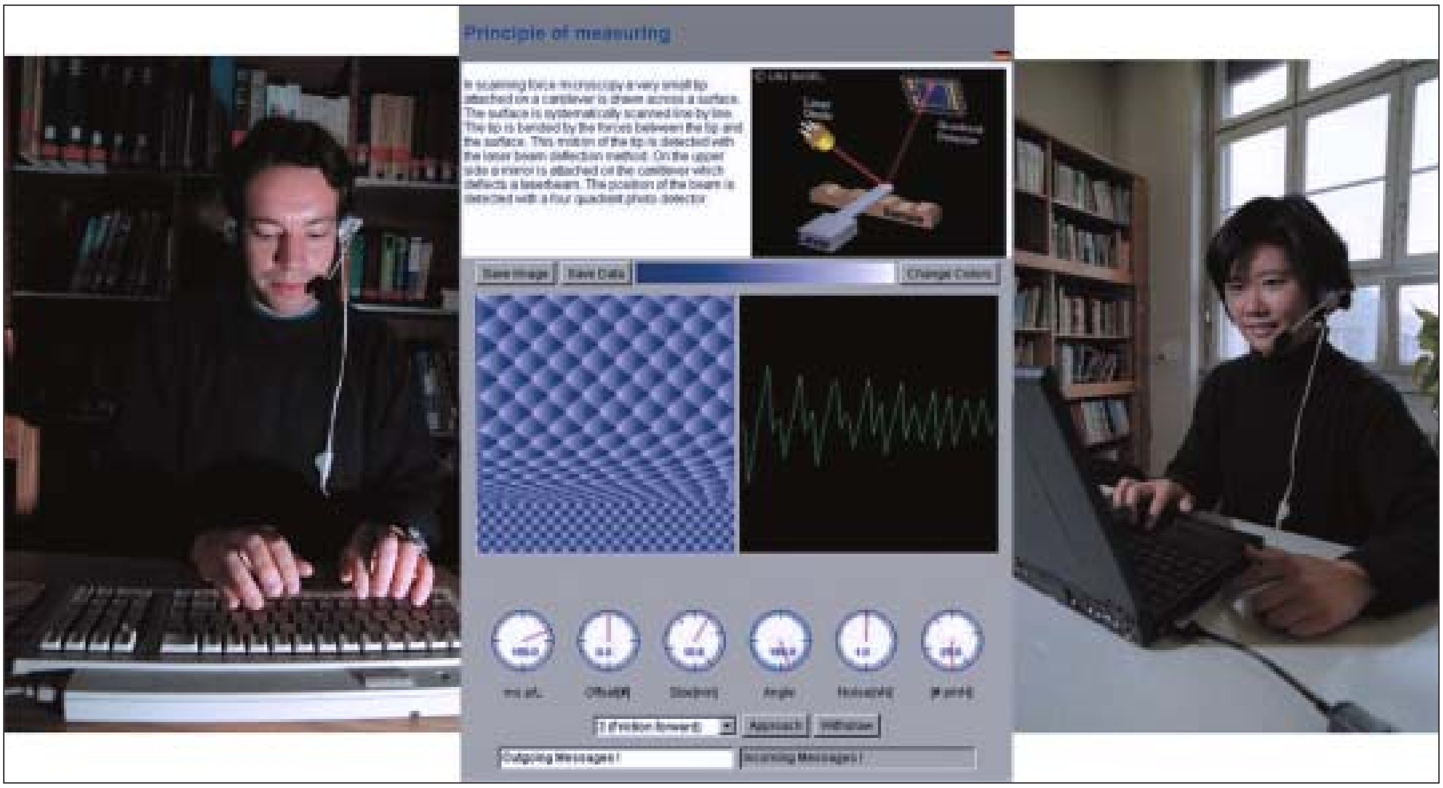

Fig. 1. Two students, located at different global locations, are operating the friction simulator module cooperatively. Both connected clients can adjust shared global instrumental parameters of the microscope. The adjustment of a parameter is broadcasted to all other students in this session. In the middle of the figure a screen shot of the multimedia module which explains physical background of the specific measurement technique is presented. The additional modules can be started with a click on the menu bar on the top of the simulator panel. The simulator is available online at *http://www.frictionsimulator.nano-world.net*

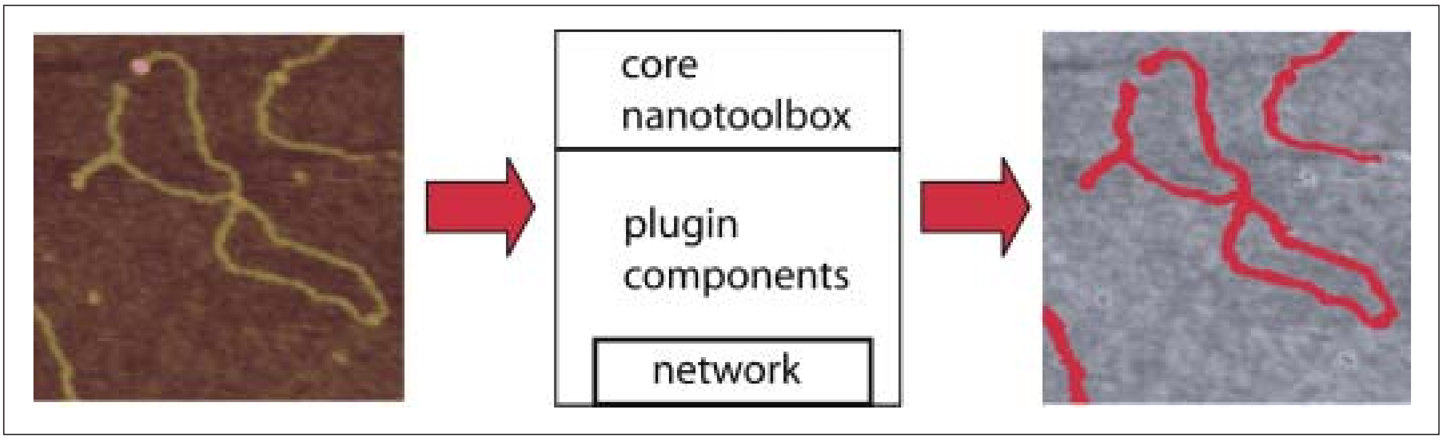

Fig. 2. This schema shows the main task of the nanotoolbox which is to analyze and visualize nanoscience data. The left image shows DNA molecules on a gold surface. The measurements were performed by M. Hegner and W. Grange from the national center of competence in research on nanoscience and published under 'Mechanics and Imaging of single DNA Molecules' in *J. Muscle Res. Cell Mot*. **2002**, 22. On the right-hand image all noise has been cut away and the DNA molecules are clearly marked in red.

data. Additionally real-time collaborative learning is supported, which means that scientists can explore and share their measurements through the Internet. An alternative to real-time sharing is the ability to export and import nanoscience measurements using HTML files. For printing purposes a PDF file can be generated. The toolbox provides batch processing which is often useful for recurring measurements.

4. Remote-Controlled Atomic Force Microscope (Fig. 3)

The remote-controlled atomic force microscope is a further step towards consistent integration of students into scientific work. This microscope [16] allows remote measuring and observing of surfaces on the scale of nanometers. An additional robotic environment allows a remote sample exchange with micrometer precision. In this way a number of researchers, teachers or students can access their own samples and share the instrument among themselves according to either a schedule or notification.

It is possible to operate the remote AFM in expert or novice mode. The novice mode allows a sample to be changed and to start or stop the measurement. The zoom factor can be changed during the measurement but

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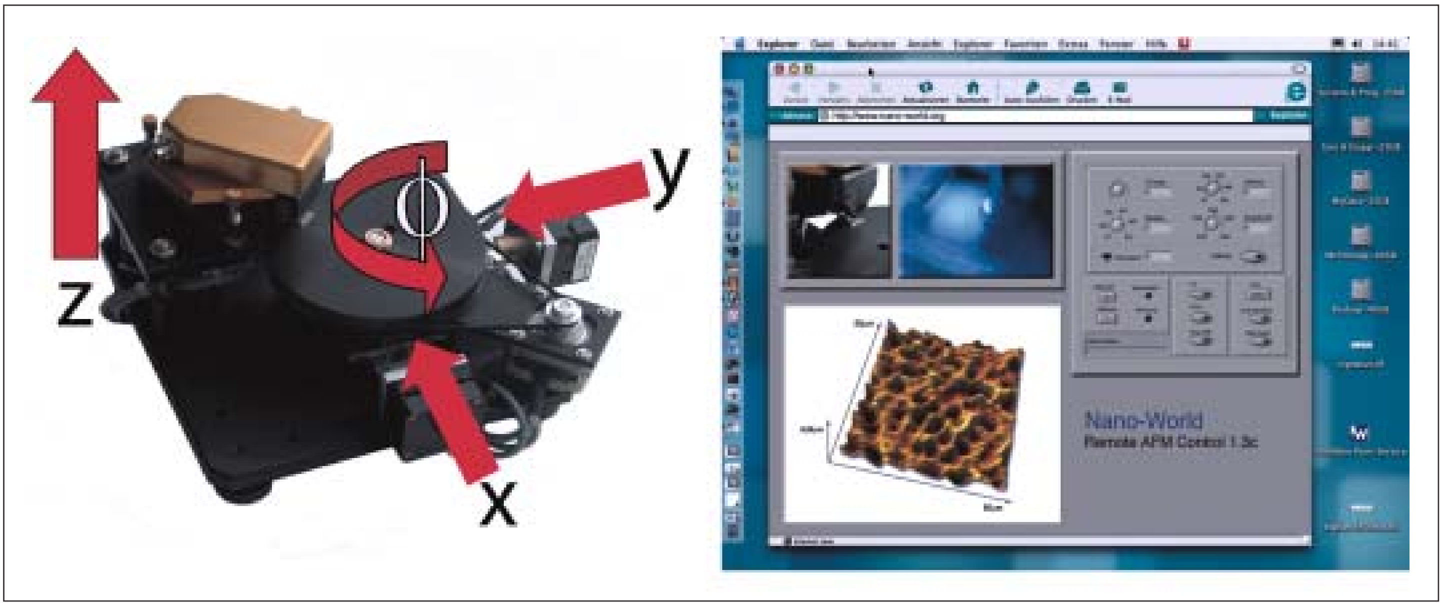

Fig. 3. On the left the microscope with the EasyAFM [16] scanhead, a sample table, and a wide range positioning system. A sample stage with four axis robotics allows automated positioning in a range of 150 mm within a tolerance of 3 micron. In the measurement panel on the right, a part of the surface of a child's tooth was observed.

an operator in the novice mode has no access to any calibration or other complex parameters of the microscope. Therefore no operations that could be hazardous for the measuring sensor can be performed in this mode. In the expert mode it is possible for the scientist to access and change every parameter of the microscope. The operator can remotely set-up a program for long-term measurements. This mode is highly sensitive and access rights are required.

5. Outlook and Future Work (Fig. 4)

Monitoring and controlling a scientific experiment from your mobile device anywhere and anytime is the goal of the MURCI-project (Mobile Universal Remote-Control Interface). Mobile devices, such as mobile phones and PDAs, nowadays include always-on wireless networking, persistent memory, minimal computational capabilities and allow the uploading of small programs that exploit these abilities. A first demonstrator site, wireless NANO-WORLD, implements the monitoring and control of an atomic force microscope (AFM) simulator [17]. As feedback from the research community has been very positive, we want to rewrite and extend the prototype towards an operational mobile client to be used by the researchers of the nanoscience competence center (NCCR).

Fig. 4. On the left the mobile device shows a scanned image with the friction force simulator. The right panel shows the parameter screen on a thin client.

The Collaborative Nanoscience Laboratory is integrated into the nanoscience curriculum at the University of Basel. In the forthcoming semester (2003/2004) the first interactive nanoscience project-week will take place. Lecturers from other universities have signaled their interest to use parts of the NANO-WORLD project in their lectures. Pharmasquare [18], a SVC partner project, is developing a new feedback and testing system named Tetrodo. This system will support an automated server-sided administration of credit points. An implementation of Tetrodo is planned in the next major release of the NANO-WORLD project.

Vitels [19] and NANO-WORLD have started a collaboration in Authentication and Authorization Infrastructure (AAI). Both are AAI Pilot Projects in the Swiss Education and Research Network (SWITCH).

Our partners from the group of Prof. H. Siegenthaler of the Department of Chemistry at the University Bern have developed an electro-chemistry module which includes simulation of electro-chemistry processes on the atomic scale.

NANO-WORLD will integrate next-generation technologies from grid-computing. In particular cooperation with the OpenLogbook [20] project from CERN will benefit from synergies in the field of virtual experiments based on grid technologies. It is planned to start an open source project with the NANO-WORLD virtual experiment framework under a BSD license [21].

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[1] Nano-World Project Page: *http://www.nano-world.net*.

[2] Swiss Virtual Campus: *http://www.virtualcampus.ch*, **2000–2004**.

[3] P. Browning, 'Zope – a Swiss army knife for the web?', *VINE-* **2000**, *119*, 61–71.

[4] C. Freiburghaus, T. Gyalog, M. Guggisberg, P. Fornaro, S. Kannookadan, H. Burkhart, T. Fink, H. Siegenthaler, H.-J. Güntherodt, 'EClimate: Creating and Motivating Virtual Learning Environment', Proceedings, Lugano, **2002**.

[5] M.-A. Steinemann, T. Braun, 'Remote *versus* Traditional Learning in a Computer Networks Laboratory', Communications and Computer Networks (CCN 2002), Cambridge, USA, November 4–6, **2002**.

[6] M.-A. Steinemann, S. Zimmerli. T. Jampen, T. Braun, 'Gloabal Architecture and Partial Prototype Implementation for Enhanced Remote Courses', Computers and Advanced Technology in Education (CATE 2002), Cancun, Mexico, May 20–22, **2002**.

[7] M. Guggisberg, P. Fornaro, T. Gyalog, H. Burkhart, 'An Interdisciplinary Virtual Laboratory on Nanoscience', *Future Generation Computer Systems* **2003**, *19*(1), 133–144.

[8] G. Binnig, H. Rohrer, 'Scanning tunneling microscopy', *Helv. Phys. Acta* **1982**, *55*, 726–735.

[9] G. Binnig, C.F. Quate, C. Gerber, 'Atomic force microscope', *Phys. Rev. Lett.* **1986**, *56*, 930–933.

[10] T. Gyalog, M. Bammerlin, R. Lüthi, E. Meyer, H. Thomas, 'Mechanism of atomic friction', *Europhys. Lett.* **1995**, *31*, 269.

[11] E. Meyer, R.M. Overney, K. Dransfeld, T. Gyalog, 'Nanoscience: Friction and Rheology on the Nanometer Scale', World Scientific, MA, **1998**.

[12] G.A. Tomlinson, *Philos. Mag.* **1929**, *7*, 905.

[13] D. Tománek, W. Zhong, H. Thomas, 'Calculation of an atomically modulated friction force in atomic-force microscopy', *Euphys. Lett.* **1991**, *15*, 887–892.

[14] E. Ong, V. Pizziconi, B. Ramakrishna, 'Interactive nano-visualization for science and engineering education', *J. Materials Education* **2000**, *21*, 27–31.

[15] E. Ong, A. Razdan, A. Garcia, V. Pizziconi, B. Ramakrishna, W.S. Glaunsinger, 'Interactive nano-visualization of materials over the internet', *J. Chem. Educ.* **2000**, *77*, 1114–1115.

[16] EasyScan AFM, mobile atomic force microscope produced from Nanosurf, Switzerland: *http://www.nanosurf.com*

[17] C. Wattinger, P. Fornaro, M. Guggisberg, T. Gyalog, H. Burkhart, 'Monitoring and Controlling Scientific Experiments: Anywhere – Anytime', *ERCIM* **2003**, 52.

[18] pharma^2: Course of Pharmaceutical Chemistry in a Virtual Laboratory: *http://www.pharmasquare.ch*

[19] Virtual Internet Telecommunications Laboratory of Switzerland: *http://www.vitels.ch*.

[20] The OpenLogbook team Ville Nennonen, Mikko Fallenius, Daniel Kjr, Andrea Hilschey, Peter Boggild, Russell Taylor, Matti Heikkurinen.

[21] SourceForge.net is the world's largest Open Source software development web site, providing free hosting to tens of thousands of projects: *http://sourceforge.net*.