Nano-World

A Showcase Suite for Technology-Enhanced Learning

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Abstract— **Over the past couple of years we have defined and implemented a variety of tools and instruments for supporting technology-enhanced teaching within the field of Nanoscience. Among others, the Nano-World showcase suite developed includes the following: a collaborative simulator for learning the basics of atomic force field microscopes; a remote laboratory which offers real-world access to experiments at the nanoscale level; software infrastructure for remote control and steering of ongoing experiments using mobile devices; interactive courseware that teaches the basic laws of physics such as force fields; a web-based platform for 3D visualizations of data collected via nano microscopes; and an interactive game for getting first impressions of atomic manipulations.**

In the paper we describe the different components and report on lessons learned from using the showcase within the university curriculum as well as an information medium for schools and public audiences. We also report on plans and first steps to interface the showcase suite with LiLa – the forthcoming library of labs.

Keywords: Remote Laboratory, Virtual Experiments, Nanoscience, 3D visualization, Collaborative Learning Environments

I. INTRODUCTION

In recent years, nanometer-scale science and technology has gained a lot of interest among researchers and the public. Boosted by the development of the scanning tunneling microscope (STM) [1] by Nobel laureates Gerd Binnig and Heinrich Rohrer at the IBM Zurich Research Laboratory, the fascination of investigating and manipulating material at the nanoscale level has attracted a large number of research groups.

At the level of atoms and molecules, we see a blurring of boundaries between classical disciplines such as physics, biology, and chemistry. Therefore, training in this new field is not only important for the different curricula involved, but is also a challenge due to its highly interdisciplinary nature. Future nanotechnologists need training in solid-state physics, molecular chemistry, analytical chemistry, and engineering.

The Virtual Nanoscience Laboratory of the University of Basel [2] consists of virtual and remote experiments, collaborative 3D visualization tools, interactive game-based learning methods, and an infrastructure that offers mobile access to remote and virtual experiments [3].

Hands-on examples, course materials, and simulations give an insight into the methods of Nanoscience and nanotechnology for undergraduate students of different disciplines.

II. VIRTUAL EXPERIMENTS: NANOSIMULATOR

A. Content

With the STM as the first Nanoscience tool accessible to researchers, it was possible to make nanostructures visible that had previously been inaccessible to sensual perception. Nano tools also allow the investigation of additional physical properties such as normal and lateral forces or optical properties. All technical approaches are based on raster scan technology: line by line, a sensor rasterizes the surface and records information, very similar to a blind person who is scanning a text written in the Braille code.

Our NanoSimulator, a simulator for learning the basics of atomic force field microscopes, is based on five virtual experiments using the raster scanning method mentioned before. Experiments implemented include friction, electrochemistry, fluorescent dipoles, imaging technologies, and non-contact AFM on Si(111)7x7 surface [4]. As the friction module is the NanoSimulator experiment with the highest usage ratio, we have a closer look at it.

Friction is one of the oldest well-observed phenomena in the history of mankind. It appears in every technical application, whenever parts are in motion. Without friction we could not walk and no moving body would come to rest, for example. Recent research could prove that it is possible to move a weight over a surface without the dissipation of energy [5]. The virtual friction experiment (see Fig. 1) can simulate this recently explored behavior, as well as the well-known stick-slip behavior at the atomic scale.

The NanoSimulator allows the direct change of the specific parameters in every experiment. The simulator can be driven in collaborative mode: all students connected are able to simultaneously view any adaptation of parameters and the respective reaction of the simulation. By adjusting the scan size, for example, it is possible to zoom into a specific region. By increasing or decreasing the spring constant of the sensor, the contrast mechanisms can dramatically change, just like in the well-studied real experiments [6].
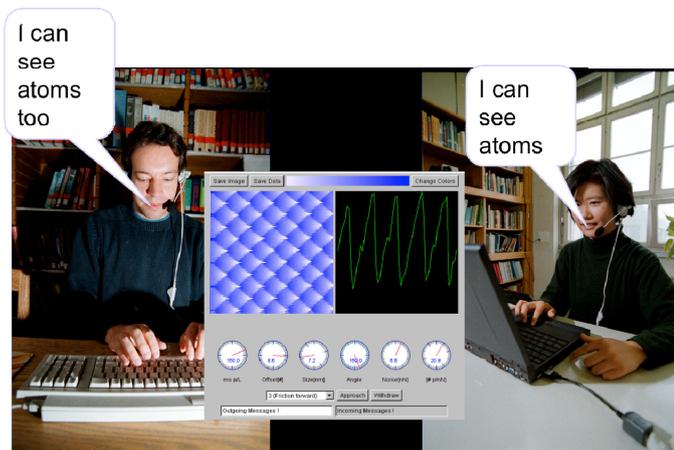
Figure 1. Friction mode of the nanosimulator. Two students observing stick-slip phenomena between a tip and an ultra flat NaCl surface. The simulation window contains several wheels for parameter settings as well as measurement results including visualizations.

B. Educational approach

All five virtual experiments follow a problem-based approach. Depending on individual skills, students get specific tasks or learning scenarios they have to fulfill using the simulator. They can act in the role of scientists and explore phenomena with virtual experiments in a similar way researchers did it a decade before in their top research environment.

The simulator makes simplifications of real-world effects, but it is close enough to practical usage. The friction mode of the NanoSimulator, for instance, allows the observation of atomic stick-slip phenomena [7] described by many researchers around the world. In addition, the NanoSimulator also correctly describes the recently investigated phenomenon of ultra-low friction [8].

Nanoscience experiments can be very expensive, which hinders their usage in education. By simulation instead, they become accessible at greatly reduced costs. Similar to aviation environments, Nanoscience students receive their basic training in a simulator context.

C. Technical aspects

All virtual experiments can run as Java stand-alone applications, Java applets or as client-server applications (Java servlets) for the collaborative mode. In the case where the actual simulation and the virtual experiment user interfaces are distributed over a network, the continuously calculated experiment data is streamed to all connected clients. Events exchanged between the client sites and the server ensure the synchronization of the application.

The virtual experiments are based on the open source virtual experiment framework vexp [9]. By using the modular and object-oriented vexp framework, new virtual experiments can easily be developed by extending the Simulator class.

D. Lessons learned

The planning, implementation, and testing of new virtual experiments are a time-consuming task. However, state-of-the-art languages such as Java have rich class libraries that support developers by providing solutions to generic problems like parameter exchange and data visualization.

Nanoscience students use simulators only if they are assigned specific tasks that they must complete and report on. In our setting, students that had to write a protocol to document their work have spent more time using the simulator.

III. COLLABORATIVE WEB 2.0 COMPONENTS: NANO3D

Nano3D is a collaborative Web 2.0 tool for the visualization of nanoscale measurements. It was developed to aid researchers in creating high-quality images and videos of their measurements (see Fig. 2) and to allow students to interactively explore atomic structures. The visualization of nanoscale worlds and the analysis of atoms and molecules offer scientists important new insights, since the function of an object is often determined by the fine details of its structure [10].

A. Content

An important goal of Nano3D was to provide researchers with a collaborative visualization platform. Nano3D allows users to easily create both individual and shared workspaces. In every workspace, they can handle the measurements uploaded, and access all visualizations previously created. The concept of easily accessible workspaces is also practical for the use of Nano3D in education. Students and pupils can be provided with a default workspace that already contains various measurements and visualizations. They can directly begin to explore the possibilities of visualizing measurements, without having to deal with importing measurements and setting up a work environment for their visualizations, as they would typically have to if they used a local installation of a visualization platform that is not web-based.

The measurements mentioned are essentially height maps of atomic surfaces created from data captured by a raster probe microscope. Various tools exist to create 3D representations of such height maps. POV-Ray [11] is a very popular tool, both because it is very powerful and freely available. Height maps can be imported and visualized from arbitrary points of view, allowing full freedom in the representation of the three-dimensional structure. However, POV-Ray is rather complex to use. The rendering of the scene is specified in the Turing-complete Scene Description Language. Text-based description of objects situated in three-dimensional space is not intuitive, and requires not only programming skills, but also good spatial sense. And even for researchers that have these abilities, creating visualizations with POV-Ray remains a time-consuming and problematic task. If not only still images, but movies should be created, additional knowledge about video encoding and publishing is required. Nano3D hides the complexities of the tool chain by using a set of flexible, parameter-oriented scene descriptions created by visualization experts. Users can control the parameters, such as viewpoint,

coloring, scaling, light and orientation not via textual input, but through interactive components (HTML forms and Java applets) that allow an intuitive understanding. Selecting the viewpoint, for example, requires just clicking a point in a three-dimensional space; choosing height-dependent coloring is supported by selecting from a display of various color gradients.
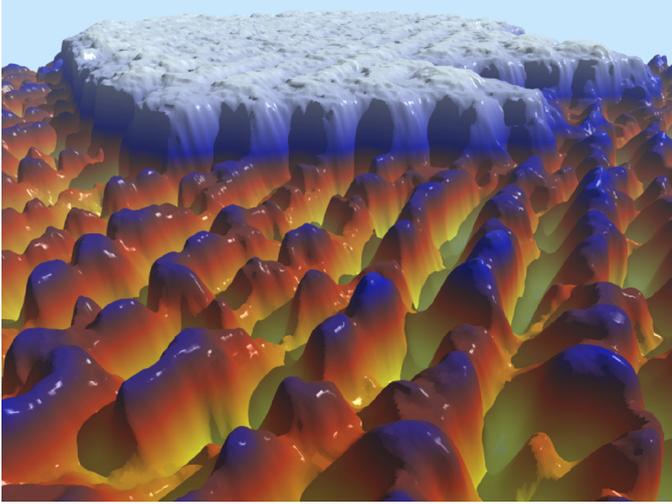

Figure 2.   3D visualization of a NaCl nano structure, created with Nano3D. The corrugations in the front represent individual atoms, the white plateau in the back is a mono-atomic ultra-flat terrace.

B. Educational approach

Nano3D allows students to work on real experiment data. However, they do not have to download and possibly preprocess this data, as they would have to if they used their own visualization solution. Real-world data is already available in the Nano3D workspace, and students can directly start exploring it through visualization.

By hiding the complexity of the tool chain necessary for creating visualizations, Nano3D allows students to focus on the cognitive impact of exploring scientific data through 3D visualization. Especially for undergraduate students whose technical skills are not that advanced, Nano3D offers the possibility to work with computer-based methods in the scientific process.

C. Technical aspects

Nano3D has two main components: a web front-end and a visualization back-end. The web front-end provides users with means to create their workspace and to upload their measurements (workspace organizer). Interactive components give the user intuitive aid in selecting appropriate parameters for the visualization. The user can edit the parameters and create and preview the respective visualization in an integrated view called render editor. The visualization back-end makes use of the ray tracer POV-Ray to generate renderings. Visualizations are created either as single images or as image sequences that are encoded into video using the open source video player MPlayer [12]. After the visualization has been created, a preview is displayed in the render editor, and the

high-resolution image or movie is available for download in the workspace organizer.

Nano3D requires a Java Servlet container (we have used Apache Tomcat [13]) and an installation of POV-Ray and MPlayer (video support can also be disabled). The application has been successfully tested on Linux (Fedora Core 5) and Windows XP. The productive deployment of the application has been running on a Linux server for over two years.

D. Lessons learned

Nano3D is in productive use since January 2007, with a total uptime of 99.8%. The Linux-based server has been running for 626 days. The main users of the service were researchers and students from the University of Basel. However, statistics show that Nano3D has received regular traffic from several German universities. The German Museum in Munich has integrated Nano3D in its exhibition about Nano and Biotechnology [14].

Nano3D is included as a component in the curriculum of Nanoscience studies, where students can get a first impression of working on measurement visualization and exploration. It is also used in events addressed at pupils and prospective students. In research weeks for pupils organized by the Schweizer Jugend Forscht (SJF) foundation, Nano3D is used to help students understand the nano-scale world of modern physics.

Nano3D has also been used in science media communication. High-end visualizations have been produced for the University of Basel's research magazine UNI NOVA [15] and for the "Small is Great" brochure of the National Center of Competence in Research Nano [16].

IV.   INTERACTIVE INSIGHT LEARNING ELEMENTS: NANOJOYSTICK

Undergraduate students of various fields making use of nano technology need a motivating but also simple introduction into the world of Nanoscience. Nanojoystick follows a game-based learning approach by offering a simplified simulation of a nano-scale environment. Users can move elementary building blocks of matter (molecules and atoms) and form new nano structures.

A. Content

Building new molecular structures atom by atom has been a strong wish in chemistry and physics for a long time. With the help of the new nano tools created in the last two decades, first steps in this direction have been taken. Notably, Wintjes et al. have demonstrated a nano-switch [17].

This recent development is brought to life in the Nanojoystick application. It allows students to directly manipulate a simulated atom-level environment.

Students control the movement of the tip of a scanning tunneling microscope in x and y direction via a joystick. In the virtual environment, they are given a nearly complete line of molecules. One molecule is displaced, and the task for the

students is to fill the gap in the line by moving the displaced molecule with the tip.

Students can control the point of view, the movement of the microscope tip and the zoom level via the joystick. The joystick provides a very direct control that many of the students already know from computer games. The time required for completion of the task is measured, and a ranking listing the three fastest students is displayed. If several Nanojoystick stations are present in the same network, they exchange scores and create a network-wide ranking.

B. Educational approach

The game-based approach allows an intuitive first contact with the field of Nanoscience. However, the use of a joystick is motivated by the practice in the scientific community. Real scientific molecule manipulation experiments needs precise planning and must be performed very carefully. Joysticks provide the necessary high-precision user interface.

In the context of science communication events such as the Sciencedays in Germany [18], the Nanojoystick is an ideal demonstrator to invite scholars to get in touch with science (see Fig. 3). The use of several stations with competition through a global ranking is well suited to involve not only single, but small groups of visitors. The high-precision control of the tip via the joystick has been appealing to both girls and boys.

Figure 3. Youngsters making their first manipulation experiments at the nanoscale level. Three interconnected Nanojoystick stations were presented at the Sciencedays in Rust, Germany, attended by nearly 20.000 prospective students.

C. Technical aspects

Nanojoystick is a stand-alone 3D application that makes use of modern graphics processing unit capabilities. It is written in Java and uses the JMonkey Engine [19], an open source scene graph for Java. The engine provides an API for physics simulation, which provides the rule set for the Nanojoystick environment.

D. Lessons learned

A game-based approach to science is very attractive for young people. Experience from several public events, most notably the Sciencedays, has shown that the interest of youngsters in a complex subject can be initially stimulated by providing a playful entry.

Also, providing several stations and thus allowing small groups to concurrently experience the application has proven valuable. The addition of a networked ranking system additionally stimulates the interest of the visitors.

V. MOBILE E-LEARNING: NANOMOBILE

A. Content

NanoMobile is a system that uses mobile devices for monitoring and controlling scientific experiments. The experiments can be both real and simulated. The system is designed to take into account the limitations of mobile devices: it does not require much user input and the users do not have to read a lot of text. It is also easy to learn how to use the software through a common user interface applicable over a wide range of real experiments and simulations (see Fig. 4). Moreover, the system optimizes the data with respect to the client device properties such as screen size and sends the data to the client in a bandwidth-saving manner.

Complex scientific experiments can run for hours or days. Supervisors of the experiments may only need to take action or monitor the ongoing experiment every once in a while. Our system aids students and researchers in using their time efficiently. They are not required to stay in the lab during the entire experiment, but are still able to monitor and control the experiments. We see several advantages such as:

- Monitoring an experiment from anywhere, at any time. Researchers and students might not always have access to a desktop computer (they may leave the lab or even the campus), and under certain circumstances, it may be impractical to carry a laptop. PDAs and mobile phones, however, are usually available all the time and are always ready to use. This makes it possible to observe an experiment while users are on the move.

- Steering of remote experiments. When errors occur, users are not required to go back to the lab to solve the problem. They can use their mobile device to restart experiments, adjust the experiment parameters, and so on. This is especially useful for long-time experiments.

- Receiving instant notification from collaborators, tutors, and experts. Simple notifications can be sent by pressing a single button. Measurements can be shared with other users instantly and regardless of their location, given that they have the client application on their mobile phone.

- Self-tests and automated notification. After setting up an experiment, a user can focus on other tasks and only go back to the experiment when notified via email or SMS

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that she needs to take action. Human supervision is only necessary in case of malfunction, extraordinary events or termination of the experiment. The mobile client and a notification system allow students and researchers to supervise their experiment in the most time-efficient manner.

Figure 4. NanoMobile remote steering interface on a PDA. Left: View of an observed surface with atomic resolution. Right: List of gauges to view and adjust experiment parameters.

B. Educational approach

We illustrate the educational approach of NanoMobile by describing several learning scenarios in which NanoMobile is used.

Scenario 1: Virtual experiments and mobile learning

We have stated that learning through virtual experiments is an important component of the Nanoscience curriculum. Many experiments take a long time to complete. If students are required to remain at the location where they have started the experiment, or if they only are able to access the running experiment when they are in proximity of suitable computing infrastructure, the motivation for persisting efforts in the virtual experiment suffers. If they are able to use their mobile devices to monitor experiment progress and take action when necessary, they can integrate the experiment supervision in whatever other activities they pursue during the day.

Scenario 2: Ad-hoc collaboration

NanoMobile allows ad-hoc collaboration in the context of an experiment. If a student conducting an experiment is unable to resolve an issue, she will typically require assistance from either a fellow student or from a tutor. NanoMobile enables instantaneous notification of other students or tutors via the clicking of a single button. The user notified can view the parameters and problems of the ongoing experiment on her mobile device and is able to directly resolve the issue. The ad-hoc nature of collaboration in NanoMobile makes involving fellow students and tutors in one's own learning effort much simpler and convenient.

C. Technical aspects

NanoMobile consists of client software for the PDA and server software that acts as a middleware between the client devices and the actual experiment.

The mobile client has four important modules. The monitoring module is responsible for visualizing measurement data. The command module allows the user to actually steer the remote experiment. The user can start, stop and pause the experiment as well as change the current experiment parameters. The notification module is a communication service that enables the user to inform other mobile users about the experiment. Several types of messages such as alert, special interest, or help requests can be sent to a specified list of receivers. Finally, the viewer module is used to toggle between views of attached web cameras. This module is of crucial importance, since it allows users to not only monitor a set of predefined parameters and conditions, but to actually see the ongoing experiment from various angles.

The four modules communicate with the experiment via the middleware layer. The middleware layer is implemented as a Java web application using the Java 2 Enterprise Edition (J2EE). The client and the middleware exchange messages via HTTP.

Clients request visualized measurement data via HTTP GET requests. To save expensive GPRS bandwidth, only the updated parts of the measurement data are sent. The measurement data in scanning type experiments (e.g.: scanning probe microscope experiments) is generated line by line. On stable network connections, there are many requests per unit time for very thin slices. This yields very good real-time visualization of the experiment. When the GPRS signal strength is bad, the delay between transmissions can be a few seconds. If the delay time is longer than the scan duration for the complete image (around 60 s), the client gets the image in one chunk.

A request contains several parameters such as start and stop line of the current slice, scaling factor and device type. Parameters are sent to the middleware as URL-encoded name-value pairs. Control commands for the experiment server are sent in the same way. The measurement data is received at the mobile client as an HTTP response. Image parameters and command responses from the experiment are included in the HTTP response as custom headers (e.g.: startline: 12, scanrange: 50). According to the image parameters (startline and stopline), the image slice is superposed to the image shown to the user. The user gets the impression of watching an evolving scan image as if she sat directly in front of the microscope.

The experiment continuously streams out raw measurement data on many channels. This image data flow can be as high as a few hundred kbps depending on the scan speed and the number of channels. As middleware and experiment server are usually located in the same LAN, only the transfer speed of the LAN connection sets a limit to the raw data stream.

To reduce the workload on the mobile client, only the data that the user wants to see at a given time is sent. To be able to

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react immediately to the demands of the user, it has to keep an up-to-date set of the uncompressed raw data matrix. The middleware component includes an image generator that creates raster images from the raw data (scaled to the client screen size). This ensures that measurement data is sent to the wireless client in a bandwidth- and transmission-cost-saving manner.

The J2EE technology provides scalability for the middleware layer to support many simultaneous clients. It also enables rapid implementation of an additional web application to control the experiment server. Web browsers of all computer platforms can display the HTML view of the servlet.

D. Lessons learned

Conducting experiments (be they virtual or real, in an educational or scientific context) has two important aspects: the required efforts can be sparsely distributed over time, and synchronous and asynchronous collaboration is often necessary. Obtaining information from and steering experiments not in situ, but from remote locations, is an important progress. By providing such remote control for ultra-mobile platforms, i.e. platforms that are always available to the user such as PDAs and smart phones, we achieve maximum efficiency in organizing experiment supervision and collaboration.

VI. Conclusion and Outlook

Our showcase demonstrates how the Nanoscience curriculum can be enriched through the use of advanced learning technologies. The simulation of experiments makes them much more accessible to students. Simulated experiments are much cheaper, can be repeated arbitrarily and require less prior knowledge than real experiments. Students can train under conditions that they will later experience in their real lab work.

Accessibility not only on a technical, but also on a conceptual level is facilitated through the use of advanced visualization and interaction techniques. Nano3D allows students and researchers to explore their measurements in three-dimensional representation. The high-end nature of the visualization makes Nano3D a valuable tool not only in exploration and interpretation, but also in publishing about the experiments. The Nanojoystick is focused more on prospective students and aims at providing a playful and intuitive access to the world of nanostructures. Experience from public events shows that the Nanojoystick is well suited for providing an interactive entry point for children in small groups. Finally, NanoMobile is a valuable tool for overcoming the restrictions that long-time experiments impose on collaboration and freedom of the supervisor. Through NanoMobile, students and scientists can monitor and control experiments collaboratively and completely independent of their location.

In a broader perspective, the most important feature of the Nano-World suite is virtualization. First, real-world experiments are virtualized in simulations. Second, the presence of users is virtualized through networked communication technologies. The result of the virtualization is a much broader availability of experimental and collaborative tools. An interesting challenge is the bringing together of the developed approaches in a single virtual space. This is the goal of the LiLa (Library of Labs) project [20].

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