

7. Education

It is a great challenge to create baccalaureate programs in nanoengineering for four-year undergraduate students. Skeptics may argue that it can't be done because nanotechnology requires competence in too many fields of knowledge for a student to gain meaningful mastery in an undergraduate career. But the future nanoengineer doesn't need to know everything about all the sciences, only those aspects of the traditional scientific disciplines that are relevant to the nanoscale. Therefore, one of the main challenges of curriculum writers is to understand which concepts may be omitted from a nanoengineering education, and which concepts must be retained and then integrated into a coherent "nanoscale story."

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INTERACTIVE, ENTERTAINING, VIRTUAL LEARNING ENVIRONMENTS

Judith Klein-Seetharaman, Carnegie Mellon University

The convergence of Nanotechnology, Biotechnology, Information Technology, and Cognitive Science (NBIC) is believed to ultimately result in a "comprehensive understanding of the structure and behavior of matter from the nanoscale up to the most complex system" [1 p.1]. In biology, high-throughput methodology now allows the accumulation of unprecedented amounts of scientific data, such as genome sequences, gene expression profiles, and structural and functional proteomic data. These advances have stirred great hopes for improving human health and performance, but the quantity of data demands convergence with information technology to interpret and utilize these data to advance human performance and quality of life. This requires an understanding of the complex interactions between the components of biological systems by both domain and non-domain experts. This is particularly challenging in the biological domain because of the massive data and knowledge accumulation. Facilitating convergence of NBIC technologies therefore

requires novel interactive, virtual learning environments that engage users from different backgrounds.

Such a virtual learning environment should be a computer system that provides all the computational facilities needed to immerse into a problem derived from any of the four NBIC domains. It should hide the intricacies of computer modeling of physical phenomena so that the user can concentrate on developing an approach to solve a given problem such as finding a cure for a disease. At the same time, the virtual learning environment must be scientifically accurate and include access to the state-of-the-art in available data, knowledge, and technology without requiring the user to bring domain expertise and extensive experience with the technical intricacies of the virtual learning environment that would present the user with tiresome activation barriers. In the above example, this requires that thermodynamic and kinetic processes of biological molecules and cells that control the dynamics of motion and morphological changes in a nanoscale should be translated to macro-scale changes in combating diseases. These in turn need to be interfaced graphically to respond to actions in real-time for the user and also allow for networked interaction between several users.

Progress to Date

Different aspects of virtual learning environments have been addressed to date. Modern biological education makes extensive use of visualization of biological processes and concepts. For example, the publication of the human genome sequence was accompanied by a CD-ROM that presented genome background as well as DNA sequencing techniques in animations [2]. However, these visualization tools are mostly designed to complement traditional teaching techniques and are not very interactive. More interaction is provided in the “Virtual Cell,” a virtual environment in which question-based assignments are given to users in a simulated laboratory [3]. A submarine is launched that immerses the user in the virtual environment of the cell populated by sub-cellular components that the user can investigate. With a toolbox, various cellular processes can be investigated experimentally. The results of these investigations and experiments allow users to solve the assignments at their own pace and through their own motivation. It was shown that this approach significantly improves authentic learning, in particular for large-enrollment general biology classes [4]. At the other end of the spectrum, realistic, fully interactive virtual laboratories have been developed to simulate chemical [5], biological [6], and recently nanoscience [7] laboratory experiments.

For inexperienced users, specific virtual laboratories may not be appropriate, because such users may not yet have sufficient insight needed for discovery and for solving problems in a virtual laboratory without the background in the specific domain of the laboratory. Insight, i.e., the capability to make non-obvious connections between the complex interactions of the components of these systems, is the main requirement for solving any type of problem [8]. Such insightful solutions can often be found in an interactive and visual virtual learning environment, as demonstrated, for example, by the fact that despite the modern numerical computing technologies, biophysicists today still use Gedanken experiments for concept development [9]. Although there are many virtual reality three-dimensional molecular models available, biochemists still use hand-made models for intuitive reasoning. Intuitive simulation is one of the most powerful approaches to creative problem solving.

Challenges—and Some Novel Approaches

In principle, a virtual learning environment could teach insight into a particular problem to users who lack background in the given problem area. Major challenges in designing such an environment are how to leverage existing but dormant learning capabilities and how to avoid frustration with the novelty and quantity of the data and concepts required to achieve the insight. It

is generally believed that human capabilities for learning can be leveraged through enjoyment [10]. Novel approaches are being developed to this end; for example, a storytelling system has been presented to fertilize multidisciplinary biological problem solving [11]. More generally, the concept of “edutainment”—the marriage between education, software, and entertainment—is currently booming (see, for example, the Edutainment Section at amazon.com). Recently, the concept of edutainment was taken a step further towards developing a software that has the potential to be a virtual problem-solving environment targeted at children and professionals alike: an interactive and visual problem-solving environment for the biological domain, BioSim, has been proposed based on game design principles [12, 13]. BioSim is described in more detail below to illustrate these design principles. The first version of BioSim describes a simple world model of the human vascular system and a biological problem that involves an infection by *Neisseria meningitidis* where the biological characters are white and red blood cells and *Neisseria* cells. The users can explore biological interactions in the biological world model by three mechanisms.

1. Role Play

The system allows the user to be a biological character in the game. Cognition science shows that role play is an important way to stimulate creative ideas. It enables the user to have an intimate connection to the character. Also, personalization of a biological character makes a game more interactive.

2. Voyage

The user can navigate through the biological system in the game, either as a character, or by using a “ship,” supporting different view angles, e.g., traveling through capillaries and tissues. Voyage allows exploration at the user’s chosen leisure, accommodating users with various backgrounds.

Figure 7.2 shows an example for a biological system. The user plays a game in which the human body is infected with *Neisseria* bacteria and the goal of the game is to cure the infection. A ship provides transportation through the body (left). A control panel inside the ship has sensing and action capabilities. Bacteria can be marked by the user with histamines, introducing the concepts of molecular recognition. Bacteria that have not been marked can divide undisturbed (gray bacteria in 1,2 on the right). When the ship approaches the bacteria (3), the histamine sensor identifies the bacterial infection and the user can mark them (color change). After marking, the user can attract macrophages that will “eat” the bacteria (4).

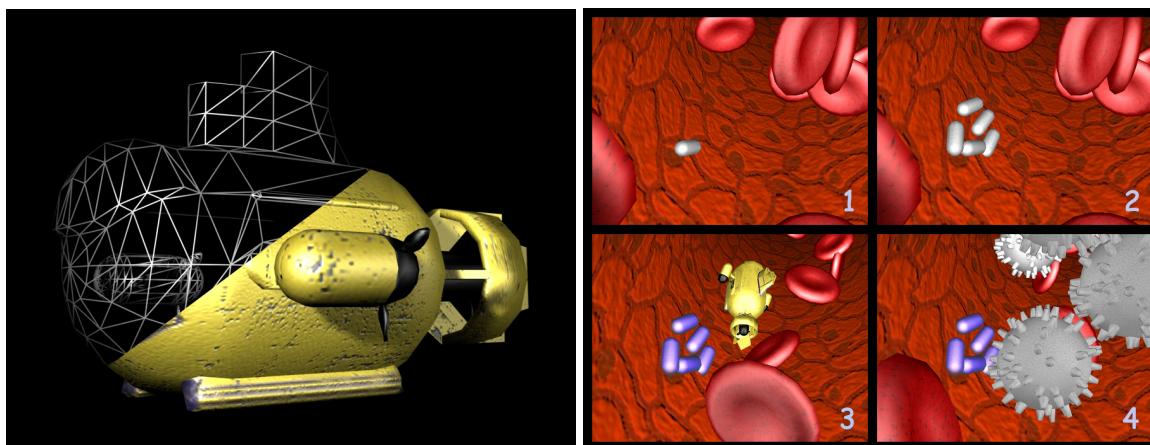


Figure 7.2. Immersion of the user in virtual learning environments.
(The figure is modified from Figure 7 in ref. [13] and is produced with permission from Elsevier.)

3. Distributed Problem Solving

The game engine allows users to play the game over the Internet so that large problems can be solved collaboratively or antagonistically, i.e., some users can play macrophages and others can play bacteria. The distributed problem solving enables diverse game strategies and more excitement of the game. The user can also choose between two aims, rather than playing the role of a single biological component only. The user can assume the roles of multiple biological characters, thus studying their individual influence on a particular aim. These aims are to induce an infection with *Neisseria* and ensure its successful propagation in the human body, or to fight the *Neisseria* infection.

The system architecture of these “characters” contains four main components:

1. Bio-behavior is modeled using cellular automata.
2. Bio-morphing uses vision-based shape tracking techniques to learn from recordings of real biological dynamics.
3. Bio-dynamics implements mathematical models of cell growth and fluid-dynamic properties of biological solutions.
4. Bio-sensing is based on molecular principles of recognition to identify objects, environmental conditions, and progression in a process. For example, each activity is determined by availability of “energy points,” which have to be carefully balanced to minimize consumption and maximize effectiveness. The user knows the status of energy points via a control panel, which also provides for the various possibilities of action. For example, in a state of high energy, the user can afford to travel actively with the ship to a point of infection. However, in a state of low energy, the user would choose to travel passively with the blood stream. This will allow the user to further develop decision making skills in a biological virtual learning environment. In the future, there will also be additional bio-sensing capabilities available through the control panel, for example, a histamine sensor (Fig. 7.2, right) and mechanisms of the immune system to distinguish self from non-self. This will allow introduction of molecular-level information. For example, the user will need to use molecular docking of the immune system’s antibody structures to those of the bacterial surface structures. This will train users to view protein structures and understand the mechanisms of complementarities of two structures. The player seeking to evade the immune system would need to develop strategies to evade antibody marking, e.g., through surface mutation. Thinking about possible strategies from each point of view will allow the user to gain deep insight into the factors controlling the health of the organism, from the molecular to the macroscopic level, ultimately aiding in the development of novel solutions for biological problems such as the *Neisseria* infection.

The specific example for a virtual learning environment described here for a problem in the biological domain (*Neisseria* infection) only represents an example for the principles of design of such systems. Different types of environments can be envisioned, encompassing any area within NBIC, implementing any specific type of problem. One of the major advantages of a virtual learning environment over traditional learning experiences with special relevance to NBIC is the ability to visualize concepts and matter that cannot be seen by the normal eye. This is particularly important for teaching nanotechnology concepts that involve the atomic scale. For example, users without scientific background can learn the concept of “smallness” and the relative range of size scales involved.

Virtual Learning Environments Enhance the Learning Experience

Virtual learning environments are meant to support strategic and creative thinking and professional innovative problem solving, and to help users to learn complex concepts and interactions. The main principle is that education is directly linked to enjoyment, thereby enhancing the learning experience as proposed by Leonard [10]. In the virtual learning environment, cross-disciplinary education will be on-demand, entertaining, and interactive, allowing focus on discovery and creativity rather than on one-way tutoring. The users can be from any background or age. Virtual learning environments support equally well the education of pre-school children, professionals with diverse backgrounds and experiences, and the general public.

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INCORPORATING NANOTECHNOLOGY INTO K-12 EDUCATION

Kristen M. Kulinowski, Rice University