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Curricular modules: 3D and immersive visualization tools for learning

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Abstract

The Center for Arts and Technology has undertaken a project designed to integrate the ideas of students and faculty from different disciplines. *Curricular modules* are created using virtual reality to illustrate six scientific principles that have traditionally been difficult for students to understand in a two-dimensional, static environment. The modules are developed by student/faculty cross-disciplinary teams. A benefit of the team approach is the mutual understanding that is gained by working with individuals with different expertise and backgrounds. © 2002 Published by Elsevier Science Ltd.

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1. Introduction

Many scientific principles are dynamic, three-dimensional (3D), and temporal in nature and, as such, hard to visualize through conventional pedagogical idioms such as textbooks and blackboards. *Curricular Modules: 3D and Immersive Visualization Tools for Learning*, a project funded by the National Science Foundation, is concerned with giving students and faculty the opportunity to collaborate on building software to visualize such scientific processes. The ability for students and faculty from different disciplines to work together, each bringing their own perspective and insights, was also a crucial element in the project, enriching the development exercise as well as expanding the potential audience of the end result. Related work can be found in [1,2].

2. Interdisciplinary collaboration

The modules were developed by small teams, each comprising three students and three faculty members. The students were drawn from the Computer Science and Design departments as well as from the specific scientific disciplines for each module. The team approach provided a rich and focused learning environment and allowed students to collectively understand and solve visualization problems. All participants developed a greater respect for the other disciplines collaborating as well as the subject matter. All the students remarked positively on the mutual understanding gained in working with other students from different disciplinary backgrounds.

The students, while working in the Center's certificate program, were able to better educate themselves about the symbiotic relationship between technology and the arts. They were able to develop an understanding of the meaning and role of technology within the larger context of the liberal arts. Students who are accepted into the Center's certificate program must take an interdisciplinary course in the history of arts and technology as well as courses in the Arts and Computer Science. Furthermore, they must complete a summer internship and then spend two semesters working on an integrative project. Throughout the program they are exposed to colloquia and symposia and the students participate in exchanges emphasizing the connections between arts and technology.

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3. Overview of the modules

Modules in six scientific subjects were created: Human Physiology, Graph Theory, Introductory Physics, Organic Chemistry and Biochemistry, Cell Biology, and Astronomy Education. The modules that students worked on were complex and abstract in nature. Initially, all participants met for a discussion of the principal concepts of the modules. Students then began to sketch out the narratives of the scientific principles, brainstorming together to visually develop possible metaphors to describe the principles. The design process was explored on three levels: as information design, as interaction design, and as sensorial design.

The Computer Science students initially focused on the possibilities and constraints of the available technologies while the Design students began to visualize with the scientific students. Design students explored components of information design by testing color, form, text and shape on the computer screen—taking into consideration legibility and clarity of the narrative. The interactive components were also tested and modified, making sure that links, input systems and calculators worked effectively. The sensorial component (force feedback) tests involved applying varying stress to visual elements within the chemistry module adding an enriching detail to the user experience. These design considerations all contributed to a virtual reality space that represented an information complex—visual form, information source, transmission conditions, the user and her/his responses.

The technology used to develop each module enabled sophisticated graphics and clear information design through immersion in a virtual reality environment (running on Windows or UNIX) or via a 3D web plug-in. Most of the modules were developed on a PC/UNIX platform using C++ and Sense8's virtual reality libraries. Some used the Sense8 WorldUp software and others were programmed specifically for the web. Those that use haptics were programmed using Sensable's C++ Ghost toolkit libraries.

3.1. Examples

The modules examine six different concepts. The first is in Human Physiology and concerns the molecular events that take place during the production and propagation of an action potential. A second concept is the relationship between molecular configurations and mathematical equations. The third concept is in mathematical Graph Theory and calculates maximal flow through a network. Another concept, in Cell Biology, is the continuous flow of membrane during exocytosis. The fifth concept is the electric potential function in Physics. The last concept is understanding the idea of a galactic center in Astronomy. The concepts were chosen because they are difficult to learn from a textbook situation and would benefit from visualization and interaction. For example, in the Chemistry module, reading about the relationship between a mathematical formula and the forces on a molecule is not as clear as watching the relationship dynamically develop. Likewise, being able to walk through a graph algorithm, testing hypotheses along the way, makes the algorithm more vivid and the understanding of the mathematical proof more complete. Several of the modules are described in more detail below.

3.2. Action potential

The molecular events that take place during the production and propagation of an action potential are important concepts for students in human physiology to understand. The operation of voltage gated channels with the subsequent flow of ions into and out of the axon is a dynamic process that can best be visualized through animation. This module allows students to see the results of opening and closing the sodium and potassium voltage gated channels during the production of an action potential. In the design of this module, students chose to emphasize a shape for the sodium ions that matches the shape of the corresponding gate, thus making clear that these gates only allow certain ions to pass through. The animation allows the students to choose the perspective from inside or outside of the axon and is accompanied by audio. The virtual environment is a 3D immersive world where the user can have a top–down or an inside view and can use stereo eyeglasses. Potassium and sodium ions are moving on both sides of the cell wall and there are sodium and potassium gated channels which open and close, causing the ions to flow back and forth. This module can be experienced in both a PC and a UNIX environment. The program was created in C, with VR libraries from Sense8. The PC uses Crystal Eyes stereo eyeglasses. The courses where the module will be used are Human Physiology (ZOO202) and General Zoology (ZOO112) (Fig. 1).

3.3. Molecular conformations

Another example comes from chemistry. It is very important for students in organic and biochemistry to understand why molecules adopt their particular geometry. Length, bond angle, dihedral deformations, and a variety of non-bonded interactions are responsible for specific conformations. In molecular mechanics all of these contributions to the total strain energy are modeled by mathematical formulas, which are minimized to find the lowest energy configuration. By using a force-feedback hardware device called the Phantom (from SensAble) this module actually allows students to feel the forces acting on an atom as they simulta-

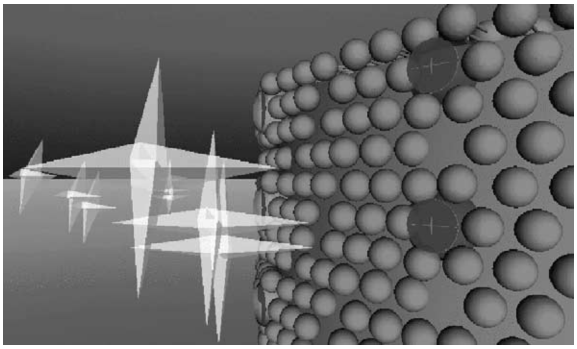

Fig. 1. Sodium ions (pink) outside the cell wall (brown), sodium gated channels (blue) and potassium gated channels (green).

neously view the corresponding graph. For example, as a carbon atom in an ethane molecule is moved away from the other carbon atom, the restoring force will be felt by the student. The virtual environment allows students first to choose a particular mathematical equation. Then students are able to pull the atom in the molecule, either stretching or compressing the bond, and simultaneously observe the mathematical graph being generated. There is an audio explanation of the mathematical equations and how they model the chemical processes. This virtual (PC) environment uses a force-feedback device so that users can actually feel the increase in forces acting on the atom. The web version of this model is in Active-x plugin. The courses where this module will be used are Inorganic Chemistry (CHM202) and Advanced Topics in Biological Chemistry (CHM417) (Fig. 2).

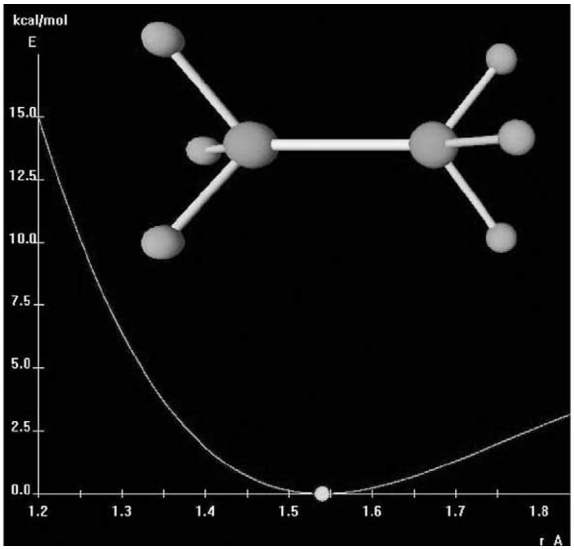

Fig. 2. As the student moves one of the carbon atoms away or close to the other, the ball on the curve traces the mathematical function.

3.4. *Maximum flow in a network*

Another module, in graph theory, helps users understand how maximum flow through a network is produced. The mathematical justification for this algorithm lies in the relationship between minimum cuts and maximum flow. A cut is produced by dividing the vertices of the graph into two sets and then adding up flows on edges joining vertices of the two sets. Cuts can be thought of as bottlenecks and so, in some sense, the largest flow will be constrained by the narrowest bottleneck. By allowing the user to pick out cuts and test them, she/he is able to achieve a better grasp of the mathematics.

3.5. *Electric potential*

Another module deals with the electric potential function in physics. Students enter information (including location) about test charges and then a 3D landscape is created where the altitude or depth at a location is the value of the electric potential. Values for this function depend on distance from the charges and on the magnitude of the charges; these values may be positive or negative. Visualizing this function as a 3D landscape shows these relationships more clearly; by varying the magnitude of the charges, by making them positive or negative, and by changing their locations, different landscapes are produced. A test charge is also incorporated into the landscape, and this test charge moves according to the gradient of the potential.

A common stumbling block in the teaching of basic electronic theory is the concept of electrical potential. The electric potential is a 3D function which, unlike gravity, students have a hard time grasping. This is probably due to two factors: one, the invisible nature of the potential and two, the fact that this potential is both attractive and repulsive depending on the nature of the charge.

This project is a virtual reality simulation of the electric potential function. Completely analogous to the hills and valleys of the gravitational situation, we develop a landscape based on the distribution of electric charges. The altitude, or depth, of the landscape, is the value of the potential function at that particular x–y coordinate; with a flat landscape corresponding to 0 V. We also incorporate a test charge which will move through the landscape according to the gradient of the potential.

The web environment is a VRML world, where the user can enter different positions and values for electric

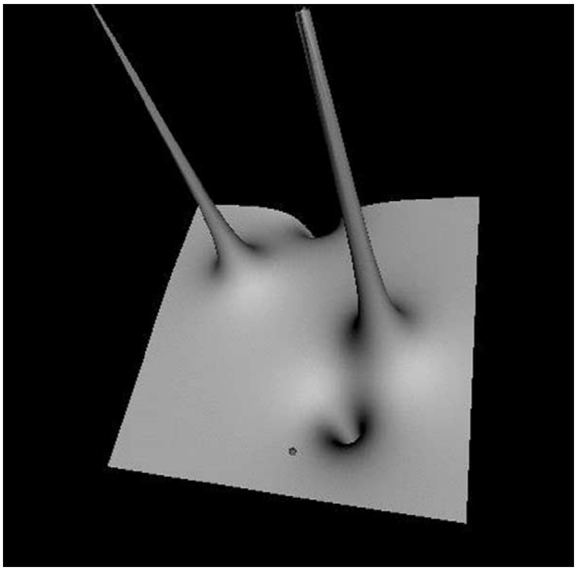

Fig. 3. 3D landscape with test charge.

charges. Upon receiving these values, a 3D VRML landscape is then created by using those charges. The user is also able to give information for a test charge, which is then animated through the landscape. The UNIX/PC version is being created in Sense8 and is similar to the web version except that users will be able to track through the environment as well as ride with the test charge. The landscape is capable of being explored with a haptic device (for force feedback). Stereo eyeglasses will increase the immersive feeling. The courses where this module will be used are Principles of Physics (PHY103, 104) and General Physics (PHY107, 108) (Fig. 3).

4. Evaluation and summary

This electronic supplement to course material is only a beginning. We will need to evaluate these experiences and build on them for the future. We will ask all students enrolled in classes using modules to complete a course evaluation form with emphasis on the modules in the classroom. So far, the students exposed to the modules in the classroom are able to immediately evaluate the user experience and respond to the clarity of the information graphics. We will also look at how to expand the modules into a broader set of materials and into an electronic classroom environment. An important component of our work will be to share our experiences electronically with others in related fields.

More information on the project can be found in [3].

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References

[1] Kriz RD. Scientific Visual Data Analysis and Multimedia, http://www.sv.vt.edu/classes/ESM4714/ESM4714.html
[2] Kriz RD, Farkas D. Using materials resources on the World Wide Web for introductory materials science teaching. Journal of Materials Education 1997;19(1&2): 111–9.
[3] Curricular Modules: 3D and Immersive Visualization Tools for Learning, http://cat.conncoll.edu/projects/Nsf