

Interactive 3D Web-Based Environments for Online Learning: Case Studies, Technologies and Challenges

Felix G. Hamza-Lup
Priya T. Goeser, Wayne Johnson
Armstrong Atlantic Univ.
Savannah, USA
e-mail: felix@cs.armstrong.edu

Tina Thompson
Mercer Univ.
Macon, USA
Elena Railean
Moldova State Univ., Moldavia

Dorin M. Popovici
Ovidius Univ., Constanta, Romania
Georgiana Hamza-Lup
Florida Atlantic Univ.
Boca Raton, USA

Abstract — **Interactive simulations and virtual environments can play a significant role in facilitating learning through engagement, immediate feedback and by providing real-world contexts. Interactive 3D interfaces have a significant impact on the user interface usability and interactivity. We present several case-studies that have evolved from actual teaching observations and have been implemented using undergraduate and graduate student research teams. The development of such simulators poses multidisciplinary research challenges and has the advantage of bringing together a diverse group of people with complementary expertise. We present case studies covering engineering, medical sciences, physics and chemistry.**

Keywords: **Computer Assisted Instruction, 3D Web Interfaces**

I. INTRODUCTION

With the emergence of novel public standards for web-based information exchange through 3D objects (e.g., X3D) we see an outburst of applications in several domains, from engineering design to 3D exploration of virtual cities to e-commerce [1].

Students in college are generally very good with technology [2]. While the current crop of college students (known variously as Generation Y or Millennials) are far more comfortable with technology than previous generations, their short attention spans and multimedia expectations may make them harder to reach via conventional pedagogical means. Cognitive studies have shown that students would engage with learning material if they could easily understand abstract/difficult concepts and relate new information to what they already know. However, lack of attention and engagement results in more failing grades, more expulsions, increased dropout rates, and a lower undergraduate completion rate.

Although a large set of teaching material was ported online in recent years, the learning efficiency of using such resources is reduced because of the inaccuracies in the electronic material [3], the paper-based way of presentation through static images and pictures, and the lack of interactivity in the applications. In such environments, the learning process is not guided, the student is lost in an

“ocean” of information, and the electronic material ends-up back on the paper in a printed format.

Our approach focuses on the development of guided learning experiences using a set of interactive simulators that have the capacity to pull the students in the learning process, offering enhanced motivation and intellectual stimulation. Since 3D visualization may prove critical for correct and rapid understanding of concepts, we explore the application of 3D technologies and standards for the development of guided interactive 3D environments for online learning.

In section 2 we present the application of web-based 3D technologies in engineering, followed in section 3 by an application in the medical domain for teaching concepts related to the human nervous system. In section 4 we explore the potential of X3D in teaching concepts in physics and chemistry. Finally, in section 5 we present some of the challenges encountered in the development and the assessment of these web-based environments. We conclude with a few design guidelines and state a few observations from our development experience with these projects.

II. ENGINEERING: THE VIEW PROJECT

Some engineering courses often seem as a collection of abstract concepts that are difficult to comprehend and apply to concrete problems and design.

In engineering, specifically materials engineering, practical laboratory experience is an essential part of education wherein students are introduced to data analysis, problem solving, testing, and scientific interpretation. However, such laboratories are not always available to students because some universities do not have the required space to set up the labs or some lab setups are too costly for the university budget. An emerging trend [2,4,5] to address these issues is to develop web-based 3D (Web3D) virtual laboratories to supplement the academic knowledge base and reinforce the concepts learned in the course. Currently, there are a number of virtual engineering labs/tools in use at several universities. To mention just a few, a virtual laboratory at John Hopkins University [6] includes experiments showing the diffusion process; a virtual torsion

laboratory has been proposed by Bhargava et. al [7] and used by the staff and students of the Cornell University. Some virtual labs are implemented using HTML combined with applets or Flash™ technology and lack a guided interaction process.

Virtual Interactive Engineering on the Web (VIEW) introduces Web3D-based laboratories, addressing the challenges of maintaining a high level of interest, enthusiasm, and information retention among the engineering major students. We chose as our focus for simulation the Tensile Testing Laboratory (TTL). TTL is a part of Engineering Materials course which introduces students to the analysis of mechanical properties of materials.

A. Tensile Testing Machine

The main objective of this experiment is to introduce engineering students to basic testing techniques required to evaluate certain mechanical properties of materials, such as hardness, ductility, and stiffness. In particular, tensile testing allows students to understand the importance of the load-strain curve in the evaluation of material properties. For continuing development of cutting-edge technologies in composites, smart materials and biomaterials, a keen understanding and knowledge of material properties as well as their testing is essential to engineering education.

The experimental setup involves a Tensile Testing Machine (TTM); our Virtual TTL specifically models an Instron™ 5566 TTM (figure 1).



Figure 1. Instron™ 5566 real TTM (left) and 3D model (right).

B. The Interactive Environment

To perform the experiment, a sample of a certain material type, is mounted into the holding grips of the TTM and held by its ends. The student selects a sample from a menu by clicking on it.

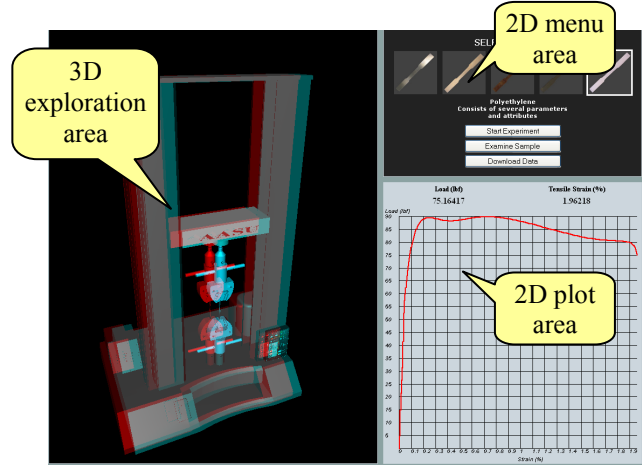


Figure 2. 3D model (red/blue rendering) and load-strain interactive plot.

Then, the student can either explore the apparatus in the left window and its components by executing virtual walks through and zooming, or s/he can run the experiment. During the experiment, the upper grip pulls the sample upward with a tensile load. The TTM controller measures the instantaneous load and the corresponding elongations (strain) and plots this information to the load-strain graph (figure 2, bottom-right). Meanwhile, the student may continue to explore the 3D model and observe the elongation and breaking process (figure 3).

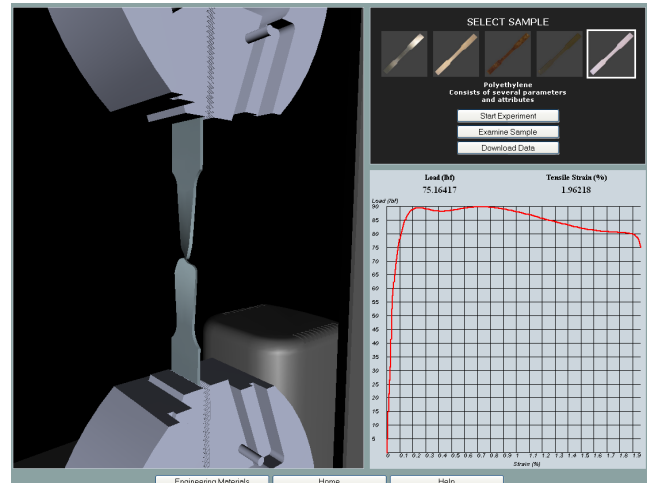


Figure 3.. A sample reaching breaking point.

The student is then prompted to download the plotted data locally. The data can be used to perform further analyses with other technical computing software, such as MATLAB™, whose capabilities allow students to manage and organize large-scale amount of information. The material properties predicted by the data will then be used to validate the concepts learned in the course.

III. MEDICINE: NEURO-PATHWAYS PROJECT

Medical students historically have difficulty conceptualizing and projecting the 3D aspects of neural pathways and embryonic organ development from two-dimensional text materials and electronic resources. While highly specific laboratory tests and sophisticated imaging techniques can be critical for the practice of medicine, the basis of a neurological exam relies on the physician's ability to visualize very complex neuro-anatomical relationships to make highly accurate diagnosis.

A. Issues with Learning, Neuro-Anatomy

The practice of medicine relies on a clinician's ability to effectively integrate basic medical knowledge with clinical experience to arrive at an appropriate diagnosis. While laboratory tests and sophisticated imaging techniques can supplement the physician's diagnostic skills, neurology is one area of medicine which relies more on the physician's ability to use knowledge of functional neuro-anatomical pathways to precisely identify the cause and location of the underlying problem [8].

Unfortunately, human neuro-anatomy is extremely complex, and functional neuro-anatomical pathways, while well described, cannot be dissected and easily visualized in an anatomy lab. Teaching students to 'see' neuro-anatomical relationships over the extent of the neuraxis (*i.e.*, *axial part of the central nervous system, composed of the spinal cord, diencephalon, rhombencephalon, and mesencephalon*) presents another level of complexity. However, the ability to internalize a 3D map of the neuraxis with the appropriate clinically relevant neuro-pathways superimposed is critical for medical students because it facilitates long-term retention of the information as opposed to short-term memorization. [9]. We hypothesize that the ability to visualize neuro-anatomical pathways in 3D significantly improves and compensates for the students' clinical deficits allowing them to localize discrete lesions and more precisely predict deficits when given the site of a specific lesion.

B. Interactive Neural Network Simulator

During the problem analysis and design phase, we decided to explore the idea of an editable tree-like network that would simulate human nervous system by showing the neural signal transmission via the shortest established route.

To stimulate student interactivity we keep the network editable and allow the students to develop their own neuron networks. A sensor-based mechanism was implemented to allow addition and removal of nodes on the surface of the 3D human model (Figure 4). Because the nodes and their indices were stored in arrays, at implementation level, every time an existing node was deleted, all array elements had to be reordered.

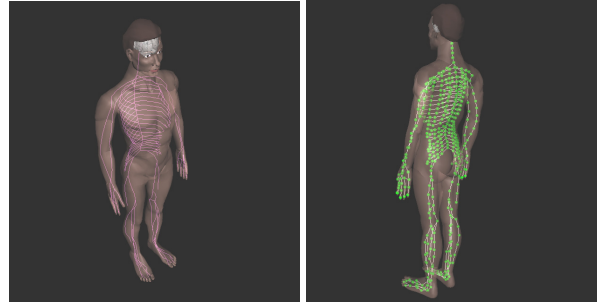


Figure 4. Neuronal Network
left-simulation mode, right-design mode.

In "design" mode, a student can load a default network and continue to add sensor locations on the skin of the 3D model. Switching to "simulation" mode, the student can explore a 3D animation showing the propagation of the nervous impulse through the nervous system.

IV. PHYSICS AND CHEMISTRY: ELECTROLYSIS PROJECT

In the following sections we focus on the development of interactive learning systems for physics and chemistry. Theoretical models and concepts understanding play a major role in the learning process in such disciplines. Some students have more developed conceptual and analytical skills while others lack such abilities.

A. Concepts and Prototypes

Chemistry and physics are disciplines that pose difficulties in understanding the concepts, actions, and phenomena when learned through the traditional method. The psycho-pedagogical difficulty comes from the process of theoretical concepts formation. 3D visualization may play a significant role in the formation of a conceptual framework for understanding complex phenomena [10]. Interactive web-based simulations have been explored recently in optics for wave simulations [11]. Some limited interactivity can be achieved with multimedia material like movies and different web-based plug-ins.

B. Electrolysis of Water

The interactive system we present next illustrates the electrolysis process, in water. Web-based lessons can be designed as simple HTML pages that include images and text. We augmented the pages with a 3D interactive simulation of the electrolysis process (Figure 5).

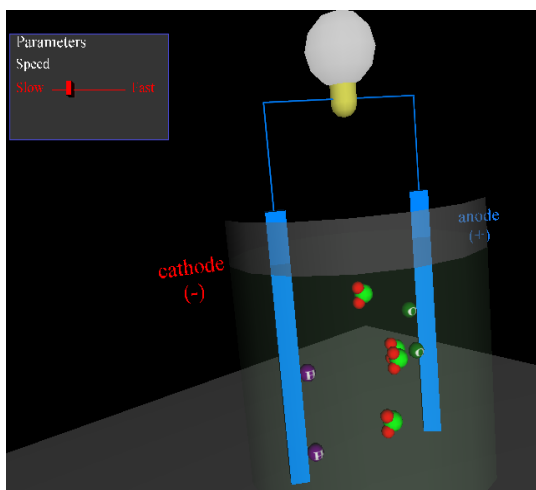


Figure 5. 3D interactive simulation.

The electrolysis of water is the process of decomposition of water molecules into ions of hydrogen and oxygen. To simulate the electrolysis of water in X3D we implement a semitransparent cylinder and two electrodes of opposite polarity that are connected to a source of electricity. We represent molecules of water as interconnected small spheres. When the circuit is closed we start the animation process by displaying electrons moving from the positive pole to the negative pole. In the process, molecules of water split into negative ions of hydroxide (HO^-) and positive ions of hydrogen (H^+). The hydroxide ions, represented as red spheres, cluster with three other hydroxide ions to form one molecule of oxygen and two molecules of water while releasing four electrons. Meanwhile, the yellow spheres of hydrogen follow the path to cathode, where they will accept an electron to become atoms of hydrogen (Figure 6).

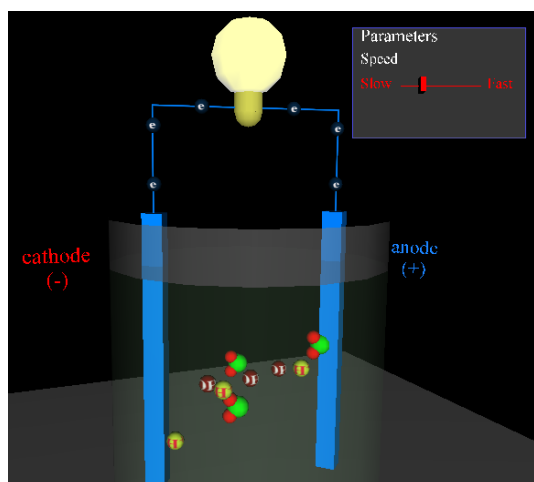


Figure 6. H_2O molecule, H^+ and OH^- ions.

The transfer of the electrons between the electrodes and the ions is emphasized by the red arrows that show the direction of ions formation. The positive hydrogen ions will

continue their movement until they meet other ions of the same type and become gaseous molecules of hydrogen.

V. TECHNOLOGIES AND CHALLENGES

Several technologies have been investigated for the development of these interactive environments. For the implementation of the 3D scenes we decide to use X3D [1]. X3D files are simply formatted lines of code. To visualize the graphical content of X3D online, a web browser needs a special plug-in. Most of the X3D plug-in vendors release their software at no cost for public use and a small license fee for commercial use. One example is the BitManagement Contact X3D player [12]. X3D plug-ins are equipped with a set of basic controls for customizing the user interface and specifying the properties of user interaction: navigational tools, graphics modes, and rendering settings, just to name a few. These features only facilitate the user in exploring the visual content. They do not provide any means of altering it. It is the X3D standard itself that allows users to dynamically modify and interact with the 3D graphical scene. There are several alternatives to implement such systems. JavaScript functions may be used to enrich the functionality. AJAX (Asynchronous JavaScript and XML) techniques are very useful in the development of an integrated web learning application.

In what follows we discuss challenges encountered by the interdisciplinary development teams and organize these discussions around the major steps of software systems development: analysis, design, implementation, and testing.

A. Analysis, Design, and Implementation

These interactive learning environments have spawned from interdisciplinary collaborations; hence, complementary expertise is needed to understand and correctly describe the problem. One of the major issues that arise in the analysis and design phases is the gap between expertises. The computer science team usually has to develop a conceptual model for the interactive simulation without a clear understanding of the overall and/or specific teaching framework in the other disciplines. The other teams understand the teaching framework but are not aware of the specific capabilities of different technologies. Therefore, a productive approach is *Rapid Prototyping* that provides a better understanding of the problem and capabilities on both sides and early feedback from the application domain experts.

From the implementation perspective, the X3D standard provides a special technology called Scene Authoring Interface (SAI) to enable the developer to dynamically modify or create X3D worlds. SAI can handle the events transfer between the scripting node and the fields of the scene's non-scripting nodes. We mainly use SAI for animations (e.g., to simulate the sample elongation during the experiment in the VIEW project), and JavaScript to provide communication between HTML controls and the X3D environment (the menus in the electrolysis and VIEW projects).

Another challenge arises from the fact that interactive environments must maintain *interactive frame rates* of operation over the web while sometimes dealing with large data sets, representing the 3D models. These datasets are preloaded in memory (at the client side) using AJAX, eliminating frame rate drops during the simulation. Data is now read directly from the memory and is not affected by the fluctuations of the network delay. Moreover, AJAX makes the preload operation unnoticeable to the user because it does not require the webpage to be updated.

Building more complex models like the neuronal network in the Neuro-Pathways project requires optimized algorithms for traversing a tree from a leaf or interior node to the root and vice-versa. This part of logic was pushed out of the X3D scope to a set of JavaScript functions. In the Neuro-Pathways project, the logic for finding the signal route was confined to recursively traveling “up the network,” finding the parent node until the root is reached.

In the Electrolysis project, the chaotic movement of the particles is generated by modifying every two seconds the coordinates for their translation using randomization and a basic step. The step can be modified from the menu presented in the interface, determining the speed of animation. The content of the lessons is stored in XML files and rendered on the web page using Extended Style-sheet Language (XSL) transformations. We use this method of rendering to allow globalization of the resources: the user has the option of choosing the language in which the information should be displayed on the page.

The 3D models have been developed with CAD software and a few additional 3D modeling platforms (e.g., Raindrop Geomagic™ and SolidWorks™)

B. Testing and Deployment

Testing has been done by students and volunteers as well as by several experts in the field. Their feedback has been promptly considered in the implementation. This is a continuous and ongoing process.

Application deployment has been done using the Armstrong Atlantic State University web and database servers. In the future, scalability and security issues may force us to adopt a different approach.

VI. CONCLUSIONS

In this paper we have presented three case studies of interactive 3D web-based environments for online learning developed using the X3D standard. For the VIEW project, this represents the initial stage of our development of a virtual laboratory for engineering materials that will be extended to other areas of engineering. The Neuro-Pathways project will evolve into a medical web-portal and, hopefully, become an online professional learning community.

For each case we have briefly presented the problem in the application domain and a potential interactive web-based solution. We have also described the technologies and the main challenges encountered in the development of these interactive systems.

All these projects have been deployed and are currently under large scale assessment and validation. However, this process takes a significant amount of time. We will report in a future article the assessment results and a quantification of the learning improvement using these systems in conjunction with traditional learning approaches.

These projects also allow interaction in a group online. As students gradually gain confidence in the team they participate in, they become autonomous and are willing to learn and acquire new knowledge; thus, they change from being dependent to being independent, and the relationships between individuals become dynamic and warm. In particular, this kind of environments is suitable for an interdisciplinary team. For example, the systems we discuss here were developed by a mixed team of computer, medical scientists and engineers, as well as a group of enthusiastic students.

There are different learning “speeds”, and they vary from person to person. Often, theory is easier to grasp than to translate into practice; or vice-versa, practical skills are quickly achieved, even without any basic understanding of the theory. In spite of these difficulties, we want to achieve good theoretical and practical skills employing such environments.

ACKNOWLEDGEMENTS

We thank Mercer Medical School for funding the initial development of the Neuro-Pathways project. Work on the VIEW project has been partially supported by a Teaching and Learning Grant 2007-08 and a STEM Grant 2008-09 awarded to the faculty at Armstrong Atlantic. We also thank all the members of the NEWS research laboratory involved in the development of these projects.

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