2010 International Conference on Data Storage and Data Engineering

Biotechnology virtual labs- Integrating wet-lab techniques and theoretical learning for enhanced learning at universities.

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Abstract—**For enhanced education at the level of University courses such as those in biology or biotechnology, one of the key elements is the need of time and expertise to allow the student to familiarize laboratory techniques in par with regular theory. The Sakshat Amrita virtual biotechnology lab project focusing on virtualizing wet-lab techniques and integrating the learning experience has added a new dimension to the regular teaching courses at the University. Establishing virtual labs requires both domain knowledge and virtualizing skills via programming, animation and device-based feedback. Challenges in the biotechnology sector in setting up a laboratory that integrates both the feel and phenomenon includes the medley of multiple techniques. This paper reports one such cost-effective process used in virtualizing a real biotechnology lab at the University-level. The major challenge in setting up an effective knowledge dissemination for laboratory courses was not only the scientific approach of biotechnology, but included the virtualization aspects such as usage/design scalability, deliverability efficiency, network connectivity issues, security and speed of adaptability to incorporate and update changes into existing experiments. This paper also discusses an issue-specific case-study of a functional virtual lab in biotechnology and its many issues and challenges.**

Keywords-virtual lab; e-learning; biotechnology virtual labs; virtual neurophysiology; sakshat amrita

I. INTRODUCTION

Software technologies developed by academic institutions as well as industries worldwide is revolutionizing the educational system. In particular, the use of virtual reality techniques is emerging as a new possibility in imparting training to students. Simulation is the most effective tool in training students in the use of sophisticated as well as complicated instruments that are routinely employed in modern biological and chemical laboratories. This technology circumvents the use of expensive and hazardous biological and chemical agents which toxic to the experimentalists as well as to the environment. Above all, the virtual lab technology is cheap as well as cost effective.

Many universities and research institutes from developed nations have realized the potential of this concept and have already launched their own virtual laboratories on the web, which are accessible to people around the world. It has already been established that the Virtual Lab enables the students to understand the underlying principles and the theory behind laboratory experiments. The procedure for operating an analytical instrument can be simulated by a mathematical and/or empirical model. Using this virtual model, the student is trained in optimization, calibration and method development for the simulated sample. E-learning plays and will play an important role in diverse regions such as India where the traditional lab facilities at Universities are not very well localized to suit requirements of all sub-regions. With multi-campus scenarios as in some Universities including ours, offering cross-disciplinary courses needs to exploit the use of extensive e-learning facilities (unpublished observation but see [3]).

Biotechnology lab courses at the richly rely upon new up-to-date content and various techniques that require a new synergy of knowledge and experimental implementation. Hence a new kind of experimental science that can be brought as a virtual simulation based laboratory is necessary. The developments of the virtual labs include study and use mathematical techniques in biology to study, to hypothesize and to demonstrate complex biological functions. However virtual labs in heavy engineering topics such as analyzing nanomaterials with high-power microscopes and lab courses in biotechnology or biology will also have to exploit multiple techniques besides simulators alone as many scenarios cannot be reproduced mathematically and also retain the "real" lab-like feel.

In this paper, we focus on the development on the virtualization of biotechnology lab courses through a combination of techniques to try completing the learning experience as that of a regular University laboratory.

II. WHY VIRTUAL LABS?

The main reasons to focus on creating virtual labs for University education are many [1]. One of the primary reasons include the cost and lack of sufficient skill-set for facing the current growth in biotechnology sector. The setup cost of laboratories puts a large overhead on the educators. The Universities also need to setup laboratories to educate sufficient target group with the details of common biotechnological techniques and protocols [5].

Another new motivation is the need to introduce and focus well explored potential virtual lab areas which use

978-0-7695-3958-4/10 $26.00 © 2010 IEEE
DOI 10.1109/DSDE.2010.22

computational methods, mathematical modeling and biophysics, computational biology and computational neuroscience. Computational biology and biophysics are upcoming areas and most techniques derive basis from real lab observations. One another intention of using virtual labs as a computational approach is to train young scientists in the field of the mathematical thinking for life sciences and related environments. Main goals of cross-disciplinary sciences include the need to ensure that the students will be able to integrate different exhaustive models into a larger framework, i.e. in the perspective of comprehensive biological systems such as cells and biological networks. The role will also give an overview of the modeling approaches that are most appropriate to describe life-science processes. For the everyday biologist, the major use of virtual labs will also be in the learning perspective of advanced but common-use simulation tools.

Virtual labs and use of virtual tools should lead to an increase the awareness of a crucial need for standard model descriptions. Most simulators and common-use tools require various formats and schema and with the explosion of data, the use of virtual labs across the country or across various countries is also intended to unite educators to work towards common model descriptions and standardization of their data.

For the biotechnology sector, a highly favoring motivation for the shift to the virtual lab paradigm is the explosion of data-rich information sets, due to the genomics revolution, which are difficult to understand without the use of analytical tools. Also, recent development of mathematical tools such as chaos theory to help understand complex, nonlinear mechanisms in biology seems to push the need for information-rich virtual labs in simulation domain. To aid further, an increase in computing power which enables calculations and simulations to be performed that were not previously possible have set a new trend in the concept and use of computing. What needed more intensive computers is plainly run through long battery-life laptops [2], which in many cases even host servers. A slightly different reason that also pushes the concept of virtual labs for undergraduate and master level education at the University level also seems to be an increasing interest in in silico experimentation due to ethical considerations, risk, unreliability and other complications involved in human and animal research.

III. TECHNIQUES – ANIMATION, MATHEMATICS AND VIRTUALIZATION

The key learning component in many biological laboratories is the complexity of the procedure and details of the step-by-step protocol carried out in the laboratory. Although some of these biological processes can be replaced by mathematical equations modeling the system, most of the "feel" is in performing the detailed procedure which is not derived from sets of equations. Graphical animations deliver a high degree of the reality to the virtual labs through their seeming closeness to the appearance and feel of the lab. Graphical animations also cut out the complexity of the modeling process by increasing the "feel" of experiment. Like the proverb goes, "a picture is worth a thousand words", animations reveal better information that cannot be easily conveyed via text alone or static illustration.

In our biotechnology virtual labs, the animation type of experiments include the use of 2D flash based animations for illustrating detailed procedures such as wet lab protocols and heavy engineering techniques that are out of scope for simulation due to various reasons like complicated equations, numerical issues in simulation, lack of modeling data etc.

Another very common and research-inspiring approach is the use of mathematical simulators to model biological and biotechnological processes or sub-processes. Although mathematics has long been intertwined with the biological sciences, an explosive synergy between biology and mathematics seems poised to enrich and extend both fields greatly in the coming decades. Among the various scenarios to study biology and disseminate information effectively and efficiently, includes the use of e-learning as a medium to offer courses..

Applying mathematics to biotechnology for virtual lab creation has recently turned into an explosion of interest in the field. The NASA virtual laboratory or the HHMI virtual labs at Howard Hughes Medical Institute or the Utah genetics virtual laboratory are some examples.

IV. MAJOR CHALLENGES

Setting and developing AMRITA virtual labs (see Figure 1) as a complete learning experience has not been an easy task. Amongst the major challenges we faced included usage/design scalability, deliverability efficiency, network connectivity issues, security and speed of adaptability to incorporate and update changes into existing experiments.

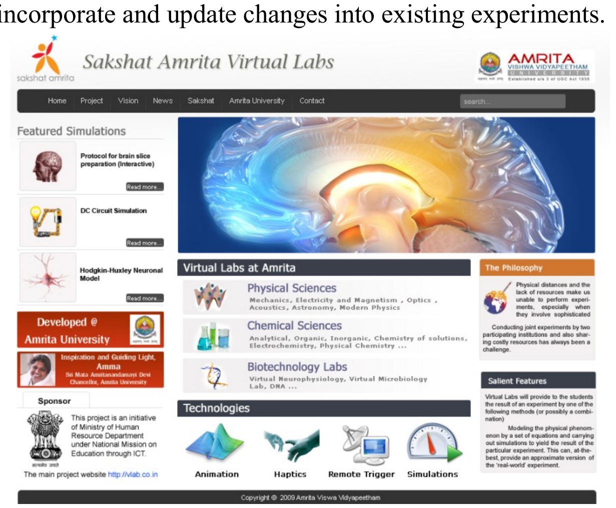

Figure 1. Sakshat Amrita virtual labs.

Owing to the scientific domain, biotechnology lends the following challenges to establishing virtual labs:

- The development of analytical solutions in the arena is limited as biological processes are typically non-linear and are coupled systems of differential equations in various forms.

- The mathematics behind models is hidden by their complexity and appears refined through simulation platforms.
- Most simulation platforms need direct hands-on experience between teachers and students.
- The number of students that can be catered at any given time is restricted.
- Besides, such courses also need simultaneous theoretical explanations which may need classroom-like scenarios with video presentations, white-board and other tools. We could overcome the issue here using a collaborative suit, AVIEW [3].
- There are not many courses in India developed for this scenario.

In order to address these issues and to overcome restrictions, we deployed virtual lab experiments webhosted simulators. The virtual lab was based on a website that was designed for favorable use within intranets and internets. However, efficiency depended on the internet bandwidth and connectivity. Our target was any campus with a download link of 256kbps should suffice. To retain this compatibility the animations had to be size-delimited. To overcome the problem, longer experiments had to be sliced to smaller portions, each loading in sequence. This was possible as we maintained the virtual lab experiments as flash animations (Adobe, USA). Having labs in flash environments allowed the scalability and access although flash based action script programming needed additional programmers and training.

Other e-learning issues such as student-teacher collaboration via chat, video interfacing etc. are overcome via AVIEW environment [3]. The intention of the virtual labs was also to extend the facility to develop an applied computational laboratory.

V. METHODOLOGY

Amongst others, the focus of having and designing virtual labs was also based on John Keller's ARCS model of motivation. Design of courses, simulations and models for computational approaches in biology will be the highlight. A lot of attention was on courses whose content will be applicable to the existing P.G. programs.

For all biotech virtual labs, we had set the following lab-level objectives as general guidelines.

- Virtual labs should be adaptive. An adaptive e-learning system is a system in which modifies its behavior (the learning process) in response to the changes in the learners input data and information gathered from various teaching process. It should be able to incorporate data and user changes as and when possible.
- Introduce and focus virtual lab areas in core computational and protocol-based biotechnological sciences.
- To train young scientists in the field of the mathematical thinking for life sciences and related environments.
- To ensure that they will be able to integrate different exhaustive models into a larger framework, in the perspective of a comprehensive biological systems such as cells and biological networks.
- To give an overview of the modeling approaches most appropriate to describe life-science processes.
- To give a practical introduction to advanced but common-use simulation tools.
- To increase the awareness of a crucial need for standard model descriptions.

The implementation of animation and simulation based virtual labs was mainly done in Action Script 3 in a flash environment in order to bring better definition to 2-D graphics. Action script allowed flash swf files as output thereby allowing both a better look-and-feel and an enhanced interactivity with the software. The physics simulator tools worked reasonably well. For one of the "more academic" simulators, we also used Sun Java based Graphic Java Toolkit to draw traces and plot graphs.

VI. CASE STUDY: VIRTUAL NEUROPHYSIOLOGY LABORATORY

Among the first labs virtualized, our preliminary studies were on neurophysiology. The virtual neurophysiology laboratory provides an opportunity for students to substitute classroom physiology course with detailed techniques and protocols of a real laboratory. Besides the material like chemicals, physiology demands extensive knowledge and experience from the instructor. For example, rat brain slicing protocol which is the first experiment (in the virtual lab) takes approximately 6-10 hours to complete training and about 2-3 weeks to train one student in a real laboratory.

With the focus on time [6] and learning know-how, we adapted the usual lab experimental protocols as user-interactive animations of the neurophysiology lab experience. The work involved both animators and programmers. For some experiments such as brain slice preparation, animations were sufficient whereas for some others such as Hodgkin-Huxley neuronal model ([4], see Figure 2.) for demonstrating behavior of single neurons, we used Java based simulator. The same simulator was embedded into other experiments such as voltage clamp protocol and current clamp protocol to allow the student to see the corresponding behavior as seen in real neurons (Koch, 1998).

Also as part of the labs, we follow a particular formatting for each experiment within the lab. The goal was to allow the student to study the theory, the approach and do a self-test before actually going into the simulator or the virtual experiment. Covering some explanations and incorporating the same theory into the actual "lab" part of the experiment has been one of the primary goals. Each experiment in the labs (especially in Biotech) opens by default with the textual theory, which can also be randomly accessed by clicking on the icon "theory".

All the control and experimental parameters are explained in the "manual". The instructor and the student are informed on how various parameters change in the experiment in the very context of the virtual experimental lab procedure. For those experiments that have both an animation learning component and simulator component, each of the user controls and the variable parameters are explained. Also included in the manual is a help that actually explains the usage of radio controls and icons covered by the experiment. The intention was to evaluate the basic info that once the student completes the familiarization process by going through the theory and manual sections, he/she can take a "self-evaluatory" quiz module that chooses to test the student on some questions based on the theory background of the experiment.

The "simulator" tab actually leads to the experiment workbench. "Protocol for brain slicing" that is actually a detailed lab process that would take 6-10 weeks for post-master's student to learn and about 3-10 hours per procedure. That experiment we have virtualized by means of an interactive action script based animation. The second neurophysiology experiment concerns the modeling of a neuronal cell. In this case we have used a Flash based learning component along with a HH-simulator of a biophysical neuron.

The "assignment" icon is the lab experiment question with which intention the student performs the experiment. An instructor version of the assignment will include a model solved question or key tips in case of a protocol-like experiment. Additional reading material and reference information and other details will be found in our "misc info" icon.

VII. CONCLUSION AND FURTHER REMARKS

As a first comprehensive experience, we have dived into what is known as "virtual labs" and the methodology and issues were discussed above. The virtual lab protocols for neurophysiological sciences have been a successful complement to the usual theoretical education that happens at our school of biotechnology at the level of masters and undergraduate education. Although the elements can be improved, our approach to virtualization has answered many key results in establishing the virtual lab features such as teacher-independent/teacher-friendly approach to e-learning.

As next stage we plan to incorporate and embed other features which are now a part of AVIEW stand-alone collaborative suite to the virtual labs to enhance learning experience. Many features currently considered to be incorporated include selective student interaction by an instructor, instructor-instructor private collaboration when more than one teacher logs in, video interface with selective response, attendance/number of hours logging, message posting, etc. Particular lab features that may enhance lab experience such as saving the state of an experiment, output lab reports in multiple formats, automated scoring and reporting are being considered for deployment.

In our experience the most vital requirement for each virtual lab is that of technical coordinators and subject matter experts whose inputs improve the lab's knowledge bank and usability. The labs will soon be online for public use via http://sakshat.amrita.ac.in and http://vlab.co.in.

ACKNOWLEDGMENT

This project derives direction and ideas from the Chancellor of Amrita University, Sri Mata Amritanandamayi Devi. This work is funded under the Sakshat project of National Mission on Education through ICT, Department of Higher Education, Ministry of Human Resource Department, Government of India. The authors would also like to acknowledge the contributions of Prof. Bipin Nair, Dr. Geeta Kumar, Mr. Kartik Iyer of the Amrita School of Biotechnology, Dr. Venkat Rangan, the Vice-Chancellor, Mr. Kamal Bijlani of Amrita E-learning TIFAC CORE, Ms. Bhavani Bijlani of Amrita University-Vocational training initiatives, Mr. Raghu Raman of Amrita technologies and Mr. Rathish of Amrita learning initiatives.

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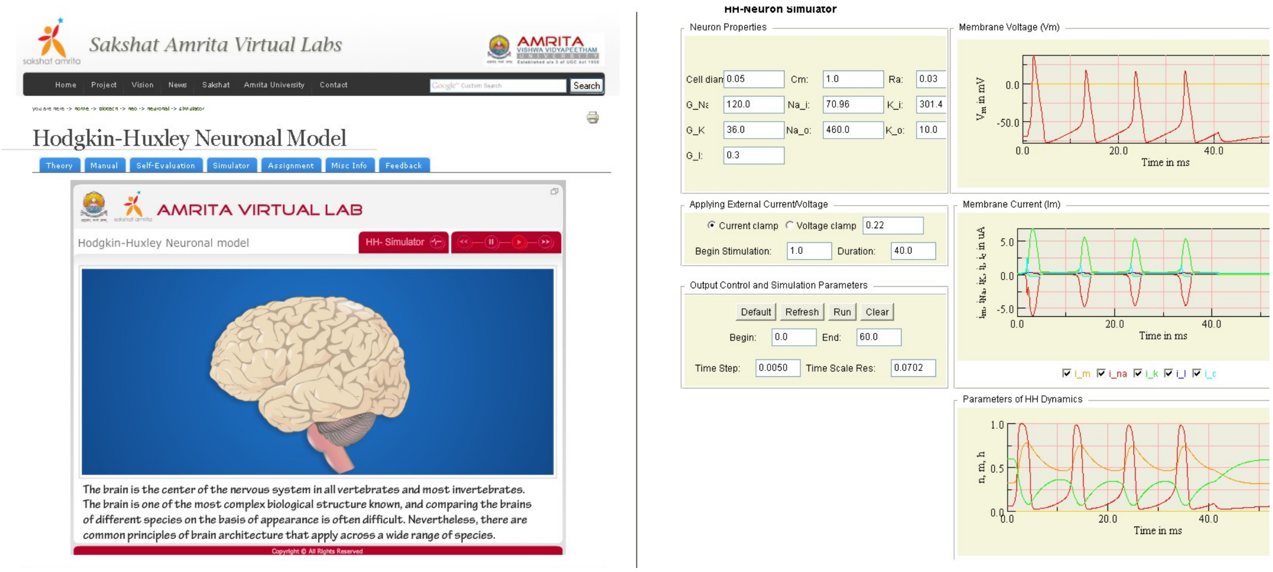

Figure 2. A sample virtual neurophysiology lab experiment.