VIRTUAL LABS ON SECONDARY METABOLIC PATHWAYS IN PLANTS

B. Ramesh Kumar[1], Vinay Kumar Singh[2], Padmavati Manchikanti[3]

[1] **Plant Metabolic Pathway Laboratory**, RGSOIPL, IIT Kharagpur, India, Email: bramesh.kmr@gmail.com

[2] **Plant Metabolic Pathway Laboratory,** RGSOIPL, IIT Kharagpur, India**,** Email: vinaysingh85@hotmail.com

[3] **(Corresponding Author) Plant Metabolic Pathway Laboratory**, Rajiv Gandhi School of IP Law, IIT Kharagpur, Kharagpur-721302. Email: mpadma@rgsoipl.iitkgp.ernet.in

Abstract

Information and communication technologies have made a big impact on education system and brought a fundamental change in teaching and learning methods. Computer assisted collaborative learning has gained popularity over the years and revolutionized science education. The remote and virtual lab in plant metabolic pathway lab provides an interactive learning based environment to the students for studying the structural and functional complexity of secondary metabolites in plants. This is achieved by a systematic understanding of complex structure and pathway in plants through series of illustrative and interacting learning tools, tutorials and simulated experiments. Further, users can remotely connect to the virtual lab to learn the High Performance Liquid Chromatography (HPLC) instrumentation based on analysis of secondary metabolites in plants (with Tea, Maize and Petunia as the plant models). Further we examined the students' understanding capability towards these labs with questionnaires designed in a hierarchical manner. This is the first systematic development of virtual laboratory on secondary metabolite pathway that encapsulates the importance of remote and virtual labs over the traditional mode of learning and describes its implementation in relation to the flavonoid pathway in plants.

Key words: Virtual labs, Secondary metabolite pathway, Flavonoids, Tea, Maize, Petunia.

Introduction

Virtual Labs

Digitized technology has enabled novel teaching strategies for laboratory classes, including new approaches to illustration, simulation, experimentation, etc. opening up new ways of creative learning for students and teachers (Domingues, Roch, Dourado, Alves & Ferreira, 2010; Herga, Grmek & Dinevski, 2012). E-learning is one of those emerging areas which allow group of students to share practical experience and at the same time allow them to practice and explore experiments using virtual laboratories. This system allows easy supervision by teachers and simplifies the experimental procedures for the students. Duffy and Mcdonald (2008) observed that the selection of the appropriate technological tools is essential for the desired learning to take place. The technology used for teaching and learning should be an integral part of the instruction (Okojie, Olinzock & Boulder, 2006). Thus systematic and thorough evaluations of these technologically-enabled lab formats are needed before their applicability and value can be understood and enhanced (Corter, Esche, Chassapis, Ma & Nickerson, 2011). A popular ICT-enabled tool in this trend is the virtual laboratory, an online environment that can be used to simulate a classroom laboratory experience (Nair et al., 2012). ICT-based education has become an educational objective in many developing nations (MHRD Sakshat NMEICT mission document at http://www.sakshat.ac.in/PDF/ Missiondocument.pdf) (Diwakar et al., 2014). Virtual laboratories are widely used for science teaching in the areas such as Engineering, Physics, Mathematics or Biology as they provide everyone with public websites to do practical experimentation from anywhere (Ma & Nickerson, 2006). According to Scheckler (2003), Virtual labs may be defined as creating a lab environment through a computer program that allows students to run simulated experiments giving an experience of performance of real time experimentation through web based access via internet. They use the power of computerized models and simulations and a variety of other instructional technologies to replace face to-face lab activities. Virtual classrooms, virtual labs and virtual environment together are important components that build an appropriate virtual education environment (Wen, 2012). Educating through virtual laboratories may overcome certain difficulties pertaining to practical experiences in science or technical subjects. It gives a realistic approach to study the mechanisms and practical work performed in the real time laboratories with various technological tools such as simulations, animations, live videos etc. However, using computers as learning materials including web sites, computer learning packages for tutorial and revision, virtual field trips and virtual laboratories also allow students to take part in the activities which are not available in the lab (Muhamada, Zaman & Ahmad, 2012). They further enable students to manipulate system generated objects and data which helps them to perform the experiments and gain experience of the learning objectives of a lab (Soni & Katkar, 2014). According to Potkonjak et al., (2016), Virtual laboratories represent distributed environments of simulations, videos, animations which are intended to perform the interactive simulation of a biological laboratory of a real system. A fully software based virtual laboratory provides an opportunity to do laboratory exercise as a part of skill acquisition process. In particular, interactive virtual laboratories are effective pedagogical resources, well suited for web based and distance education (Dormido, Farias, Sanchez & Esquembre, 2005).

Virtual laboratories for biological experiments have been in use for the last few years. While practical E-learning approach cannot completely replace hands on training in the biological sciences it assists students in forming an easier association between the textbook theory and practical lab experiments (Scheckler, 2003). Breakey, Levin, Miller and Hentges (2008) developed a virtual genetic mutation laboratory to study the effect of mutations across different model organisms. These labs were supported with advanced molecular biology technique such as gel electrophoresis and DNA sequencing methods which enabled students to analyze the data and complete the experiments at their own pace. A virtual microscopy laboratory was designed with emphasis on the analysis of virtual botany slides (Bonser et al., 2013). These were found to be helpful to replace traditional microscopy laboratories with the help of software which simulates the use of a real microscope and enabled students to change parameters of a microscope such as magnification. Further the students can change the placement of an image of whole specimen at the top of the slide which makes these virtual labs a unique component and may be better than traditional microscopy labs. Online virtual bioinformatics laboratory was designed to provide hands on laboratory experience on bioinformatics tools (Weissman, 2010). All the students were given individual assignments related to protein sequencing tools such as BLAST which were accomplished by these virtual labs through collaborative online learning. Ray, Koshy, Reddy and Srivastava (2012) developed virtual lab on proteomics to make the users familiarize and to gain hands-on experience on advance concepts of various proteomics techniques and their application in various biological samples. Based on the development of modules for technical details and simulations for experimental procedures, technologies for protein separation, identification and characterization generally used in proteomics research have been explained. Likewise many virtual laboratories based on proteomics study have been created such as Virtual Mass

Spectrometry Laboratory, ELISA Bio-interactive Virtual Lab, and NMR tutorial. The remote and virtual labs have made a paradigm shift in the learning methodology with great ease and convenience to the students in learning the subject. A Virtual biology laboratory through scenario based learning was developed to enable students to understand the concept of mitosis in cloning technology in an easy and interactive way (Muhamada, Zaman & Ahmad, 2012). Such an integration of virtual technologies and scenario based learning application was found to be very effective and increased students potential related to animal cloning and tissue culture. Another study was conducted on performing the Virtual Gas Chromatography Mass Spectrometer (GC-MS) from outside the laboratory through internet (Waller & Foster, 2000). The operating of the instrument allowed the students to collect useful data and get a realistic feeling of a real time laboratory.

The above literature shows that teaching biology across different areas was made much more interesting with the integration of virtual labs through interactive simulations and animations (Huang, 2004).

Development of Virtual Laboratory for Secondary metabolites and Flavonoids in Plants

Secondary metabolites are low molecular weight compounds which play an important role in the interaction of the plant with its environment. During growth plants are exposed to various kinds of biotic and abiotic stress conditions such as UV, salt stress, drought, metal stress, pathogen attack etc. These stress conditions induce the accumulation of secondary metabolites in plants.

The biosynthetic pathways characterize the nature of compounds present in plant system. Secondary metabolism in plants involves various classes of compounds depending on their structural variation. Among all of the secondary metabolites produced by plants, flavonoids are the important class of secondary metabolites which are credited with so many or such diverse key functions in plant growth and development (Gould & Lister, 2006). The flavonoid biosynthetic pathways produce complex classes of compounds depending on different structural configuration such as anthocyanins, flavones, flavonones, flavanols and flavonols. These compounds are obtained by the enzymatic reactions based on hydroxylation pattern, addition or removal of electrons, cleavage of bonds etc. In order to understand the complexity of the pathways, students need to focus on the enzymes responsible for particular reaction in the biosynthetic pathway and proper elucidation of the structures. These are difficult to memorize and students should regularly practice all those complex structures in order to understand the structural functional relationship. So far, no attempts are made in using a web based technology and remote laboratories to execute experiments related to identification, extraction and purification of secondary metabolites (flavonoids) from a given plant system. The attempt to make students learn the complexity of the pathways and the extraction protocols in a simplified manner has been the purpose of the present study. The implementation of these virtual laboratories on secondary metabolite study not only simplifies the structured learning through color coding schemes but also gives an insight about the extraction procedures and methods routinely used for flavonoids study in plants.

Methods

Experimental Study

The virtual lab has being implemented on the Sakshat portal hosted by Ministry of Human Resource Development, Government of India which allows the administrator to upload content and manage the web pages. All the details regarding the experimental protocols, simulation, based experiments and remote analysis of the virtual labs on secondary metabolites in plants can be accessed through the link given below: http://iitkgp.vlab.co.in/?sub=79&brch=262

Before developing the objectives for virtual laboratories on secondary metabolites in plants, a survey was done in some universities and colleges regarding the curriculum at undergraduate and post graduate level. Secondary metabolism in plants is a part of their curriculum among Botany, Plant Biochemistry, Genetics and Natural Products related subjects. Following a brief interaction with the students regarding the subject orientation and teaching methods employed by the teachers' and faculties, some aspects were identified;

- There is no interactive learning related to biosynthetic pathways as power point slide presentation was provided.
- The experiments in the laboratory were performed in a group with limited use of organic solvents and apparatus to avoid wastage of resource.
- Students' were rarely given a chance to handle the instrument individually as high-end instruments are strictly handled by faculty members only. So, they were unable to explore the instrument facility and couldn't follow some of the procedures used for quantitative and qualitative tests.
- Limited laboratory time led to inefficient learning and often students become disheartened as there is no hands-on skill development.

This feedback has been useful to plan our objectives accordingly and trace out the areas that need to be focused. The objectives of our virtual labs were designed from basic to advanced level to enhance the conceptual learning of secondary metabolism in plants. These labs were designed based on the steps represented in Fig 1.

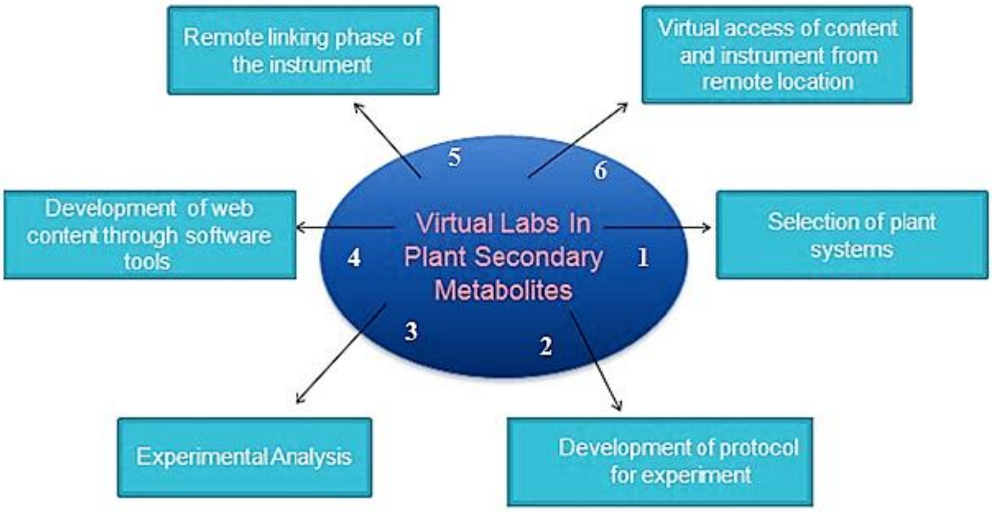

Figure 1. *Systematic approach for developing Plant Metabolic Pathways Virtual Laboratory*

Remote testing of our instrument was done in our lab from outside locations prior to the demonstration at different institutes. These labs were demonstrated at various universities across India such as Sri Venkateswara University, Tirupati, Jadavpur University, Kolkata, Bidhan Chandra Krishi Viswavidyalaya, Nadia, KIIT University, Bhubaneswar, some higher educational institutes like National Institute of Technology, Rourkela, IIT Bhubaneswar, Bhubaneswar and major research institute on plants such as National Botanical Research Institute, Lucknow. The laboratory requirements for these students include the isolation of plant extracts from different plant sources, purification and structural characterization of the isolated compounds with analytical techniques. A set up was established in every laboratory for the online practical classes and demonstration. Students' working in the laboratory team consists of 8-10 members. The virtual laboratories classes were divided into two sessions:

- Explaining the significance and implementation of simulations and animations to complete various objectives of the plant metabolic pathway labs which enhances the learning skills.
- Ability to operate the HPLC instrument from outside the laboratory through remote linking. This allowed the users to operate and handle the instrument in a safe

environment and enabled them to repeat the experiments again and again to get accurate results.

In the foregoing text the development of the virtual laboratory in terms of selection of the plant systems, objectives, software design and remote lab are outlined. The hosting of the database at the Sakshat portal provides a link for universities and colleges to access the laboratory using user ID based authentication mechanism. Following this instructional procedures have been developed to facilitate the online access of the virtual laboratory. Using focused group interviews (of about 100 students) feedback was sought on this mode of education on a questionnaire developed.

After explaining and demonstration of our virtual laboratory sessions, students were provided with questionnaire to collect individual opinion and feedback. The questionnaire consists of ten questions which was designed in order to check the understanding ability of the students and as well as to see whether these implementation of virtual labs in secondary metabolism is sufficient enough to make them understand the concept. Many questions were raised during the experimental demonstration of the virtual laboratories and remote linking of the HPLC instrument for which a separate session was organized for the students and staff members. The questionnaire was designed which asked about the lab effectiveness, learning styles, rating of the online remote linking and time spent on understanding the subject in a virtual mode.

Selection of the Plant Systems used for the study

Flavonoids are the important class of secondary metabolites distributed throughout the entire plant kingdom. Tea, Maize and Petunia were selected as model plant systems for this study. The flavonoid biosynthetic pathway is well characterized in Maize and Petunia. Tea has good amount of flavonoids accumulation which play a crucial role towards human health benefits. The biosynthetic pathways are crucial for the characterization of various class of secondary metabolites distribution throughout the entire plant system.

Objectives of the Experiment

The virtual laboratory created for the secondary metabolites lab has been divided into several objectives. These objectives will provide complete details to the students in the relevant area beginning with theoretical framework with regard to the subject, the procedure required to perform an experiment, quiz based module for self evaluation. The objectives are arranged in such a manner that students will get a basic idea starting with the fundamental concepts and slowly building up their knowledge to the current level. The objectives used for developing these virtual laboratories and an overview of the tabs designed for all objectives are represented in Fig 2.

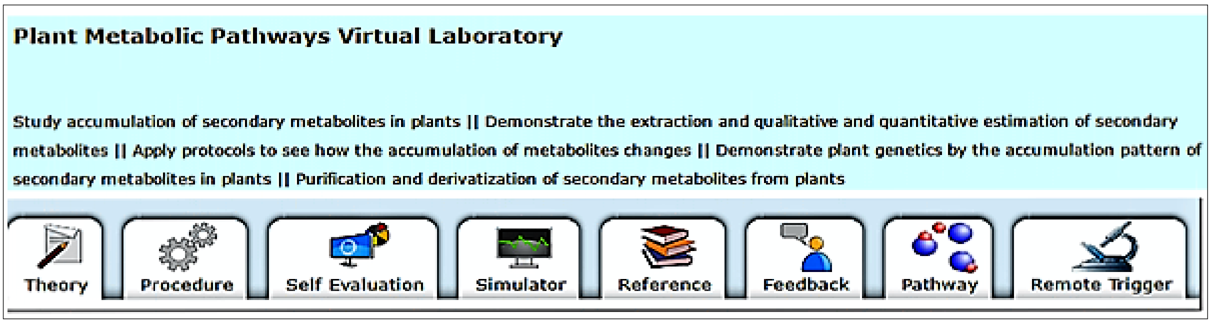

Figure 2. *An overview of the objectives and design of tabs for Plant Metabolic Pathway Virtual Laboratory*

Software applied and Database design

Adobe flash player was used for creating simulation based experimental protocols in a stepwise manner. Various images of the biological apparatus were chosen from standard books and animated diagram was made for all of them. Chemdraw software was used for drawing of various complex biochemical structures involved in the flavonoid pathway. LC solution was inbuilt software provided with the HPLC system.

Remote Laboratories Design

HPLC instrument was used for remote connection to the global users. An IP address (details available on the web page) was obtained from network administrator of Communication and Information Centre (CIC) department, IIT Kharagpur in order to connect to the HPLC instrument. Once the IP address is typed in the address bar, it will take into the home page of HPLC instrument home page window screen which will ask for log in details (user id and password). After entering the details, the users can log in into the HPLC system with an interface same as that of the real system. HPLC instrument has several important functional parameters such as LC running time, pressure, flow rate and concentration of the solvents used. Once the system is on, the users from the remote locations with the permission of person handling the instrument would be able to change some of the above mentioned parameters values according to their experimental requirement and observe the separation of compounds in the chromatogram. After the experiment is over, the remote user can view the result and can raise any query to the student who is in the actual lab.

Instructional Procedures

About 100 students participated in virtual education on secondary metabolites from plants. The student group comprised of undergraduates, post graduates and some research scholars. A large group of the students were from plant biology and pharmacology disciplines. The laboratory sessions were divided into two sessions as mentioned above in the text. The demonstrations for these virtual labs were presented to these students. All internet connections were checked thoroughly in the PC's. Before getting into the experimental details, students were provided with a lecture regarding the significance of a virtual laboratory as an educational tool and its utilization with respect to secondary metabolism. Then for each of the objectives, presentation was done in an elaborated manner discussing all the biosynthetic pathways, extraction procedures, and simulation based experiments. Data collection methods were conveyed to all the students. Self evaluation tab was designed for each objective to test students' efficiency in terms of their understanding abilities of the specific objective. For remote linking of the HPLC instrument a step by step protocol were provided for all the students and explained. The protocol describes about functioning of the instrument and setting of various parameters from remote location. One of the most important criteria is that one person is always with the instrument in the actual lab and monitors all the changes made by the users from outside when they are connected. Before analysis, a remote user has to communicate through email to the corresponding person in the lab about the time of analysis and the sample details. The person in the actual lab will respond to the communication and will give the user a slot for his sample analysis. Then on the specified slot date, the remote user will be connecting to the instrument and get the HPLC system ready from his end by entering the parameter values according to his requirement. Once the system is ready, the person sitting in the actual lab has to inject the sample in the injector of the HPLC instrument which is a manual process. After injecting the sample, the analysis will start and continues up to 20-25 minutes. The user from outside will be able to observe the elution of the compound peaks in the chromatogram of the HPLC in his Desktop. This process enables students to observe the results and they may request for result which may be send for further use.

The questionnaire has a separate module for evaluating the performance of HPLC. Some of the queries posed to the groups are related to problems students encounter while connecting the instrument from a remote location through Internet, continuity of link, to what extent they have control over the instrument (i.e., whether they were able to edit/set the parameters of the instrument during the experiment), whether absence of instructor is felt at any point of time while performing the experiment, whether the results obtained from the virtual HPLC instrument can be correlated to the results obtained with actual instrument in the lab, time taken for evaluation individually as well as in a group.

Results and Discussion

The animation based demonstration of the experiment help them to understand the procedure required while performing the experiment either in real lab environment or an experiment initiated through remote lab. This approach for demonstration has been followed throughout all the objectives of the experiment to provide better understanding of the secondary metabolic pathways in the given plant systems and enhance the learning skills through various software tools and simulation based protocols. Remote labs are upcoming development in the field of science education but progressively their numbers across various disciplines has been increasing (Nedic, Machotka & Nafalski, 2003). The problems faced by the students in conventional labs regarding the equipment availability, lacking of practical skills and hands on experience with the latest instruments is solved up to some extent. But to operate or to follow a protocols discussed in a remote laboratory, every educational institute should have proper internet facility which is still lacking in some the colleges and institutes located in the rural areas. The major objective for implementing remote and virtual lab in secondary metabolic pathways in plants has been to make the learning environment bit innovative and interacting i.e. user friendly. Virtual exercises are paired with activities in a real laboratory; the students are in an environment that facilitates the development of higher-order thinking skills because they are not bogged down by details of process or technique (Woodfield et al., 2005). The objectives of the experiments are arranged in such a manner that the students can get a basic understanding of the role of flavonoids which reaches to a molecular level interaction as the studies progresses.

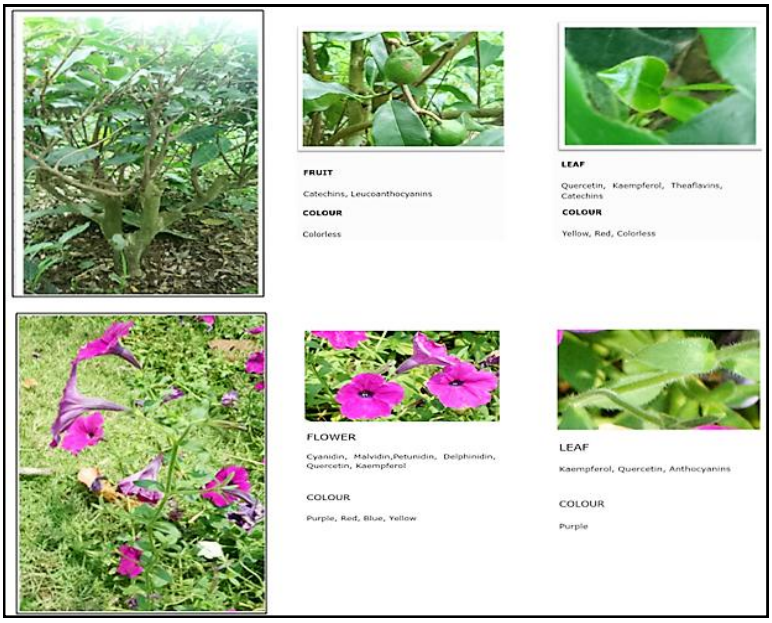

Figure 3. *Animation module for accumulation of flavonoids in various parts of Tea and Petunia*

Animation was created in such a way that if an user can click on different parts of the plant (root, stem, leaf, flower and fruit), they will be able to see the names of the flavonoids present in each specified part of the plant along with the color of the compounds, shown in Fig 3.

Pathway tab was designed to illustrate the biosynthetic pathway of flavonoid in plants. The pathways were represented with enzymatic steps and structural changes i.e. hydroxylation pattern, addition or removal of electron etc. The animation created in such a simplistic manner that even a basic learner from non biological background would be able to understand the steps of the biosynthetic pathway after repeating for 3-4 times. A home page has been created so that a user can click on the start button in order to get the enzymatic conversions of the biosynthetic pathway. An example of the first step involved in flavonoid pathway is shown in Fig 4.

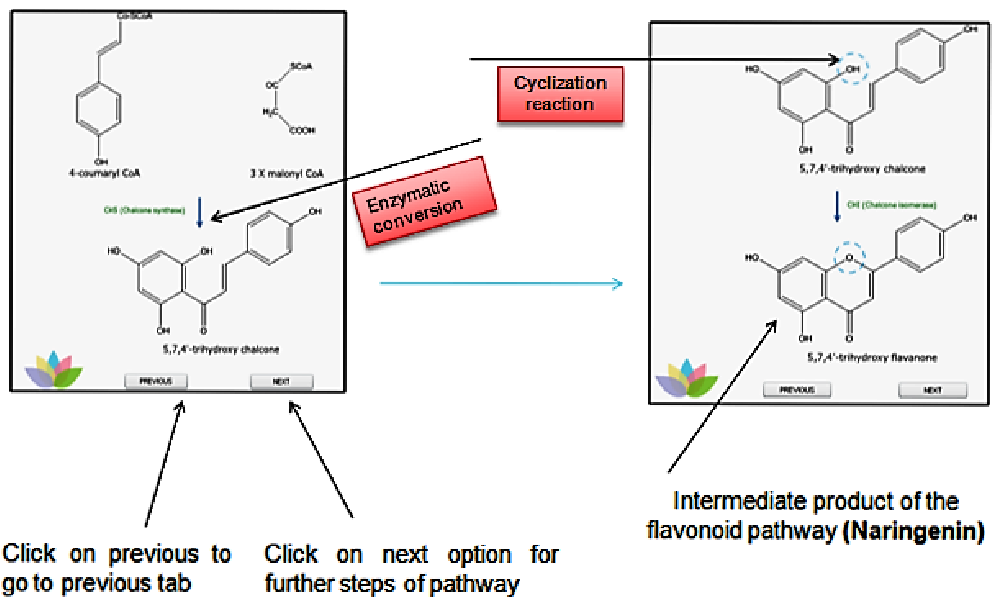

Figure 4. *An image of the initial step of the flavonoid biosynthetic pathway in plants*

The flavonoid pathway further gives rise to four different branch pathways such as flavone, flavanone, anthocyanin and proanthocyanidin pathway depending on their structural configuration. The users can click on the home page of each individual branch pathways for which systematic step wise representation of enzymatic conversions are provided. Such an interactive learning of the flavonoid pathway along with their branch pathways is developed for the first time in the virtual laboratory tutorials which are shown in Fig 5.

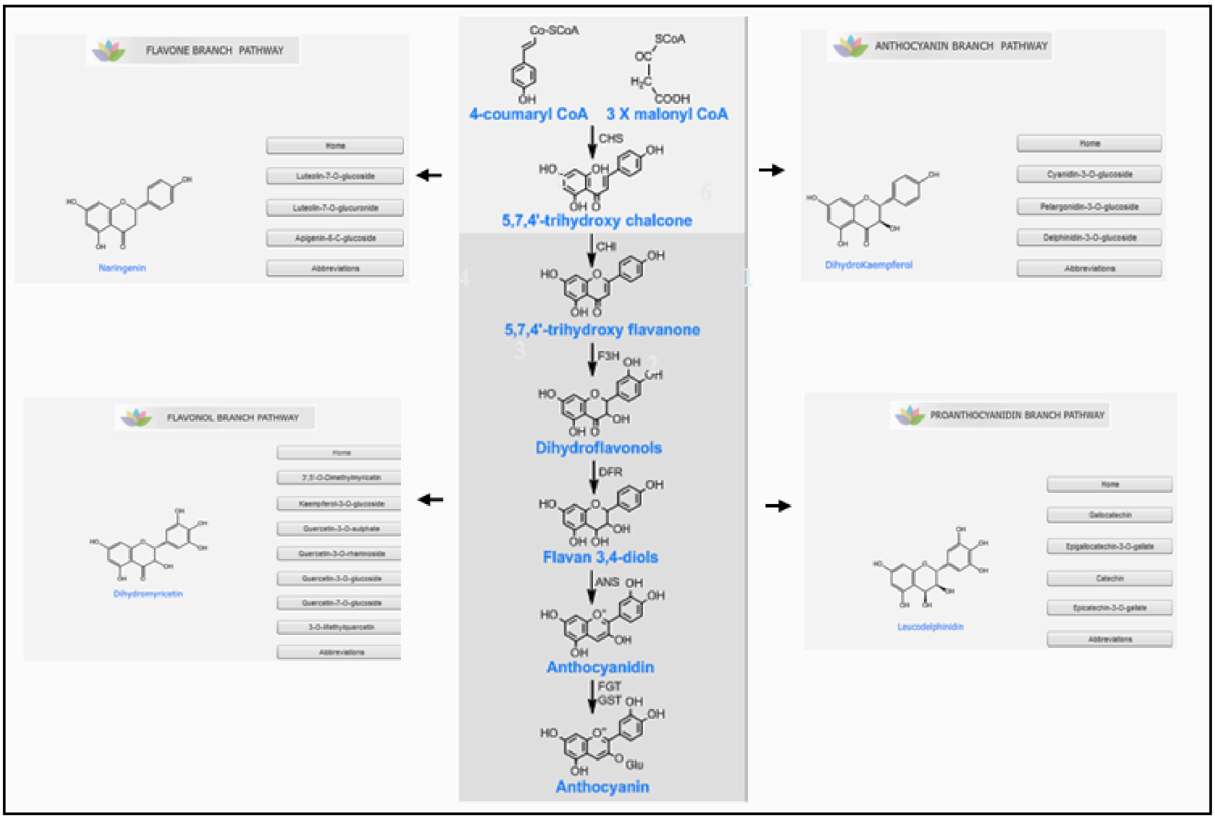

Figure 5. *Structural representation of the flavonoid and their branch pathways*

Tea plant accumulates lots of secondary metabolites in them which known to possess good biological properties. Various classes of flavonoid compounds are present in tea. Tea flavonoid pathway, for the first time is being represented fully through our virtual lab. Homepage of the Tea flavonoid pathway is shown in Fig 6.

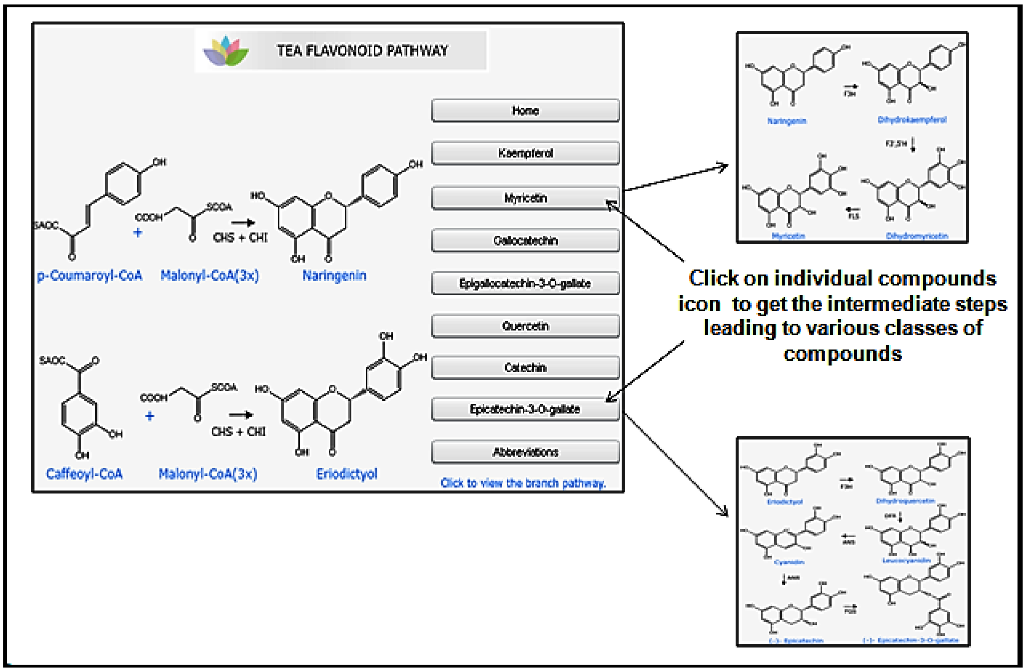

Figure 6. *An image of the homepage of the Tea flavonoid pathway*

Qualitative and quantitative test of the plant extracts by using various organic solvents and color reactions were designed through simulation. All the experimental simulations are designed in such a hierarchical manner that a student can repeat the steps with ease to evaluate his findings without time constraint. A brief pictorial representation of the steps involved in extraction of flavonoids from Tea plant is depicted in Fig 7.

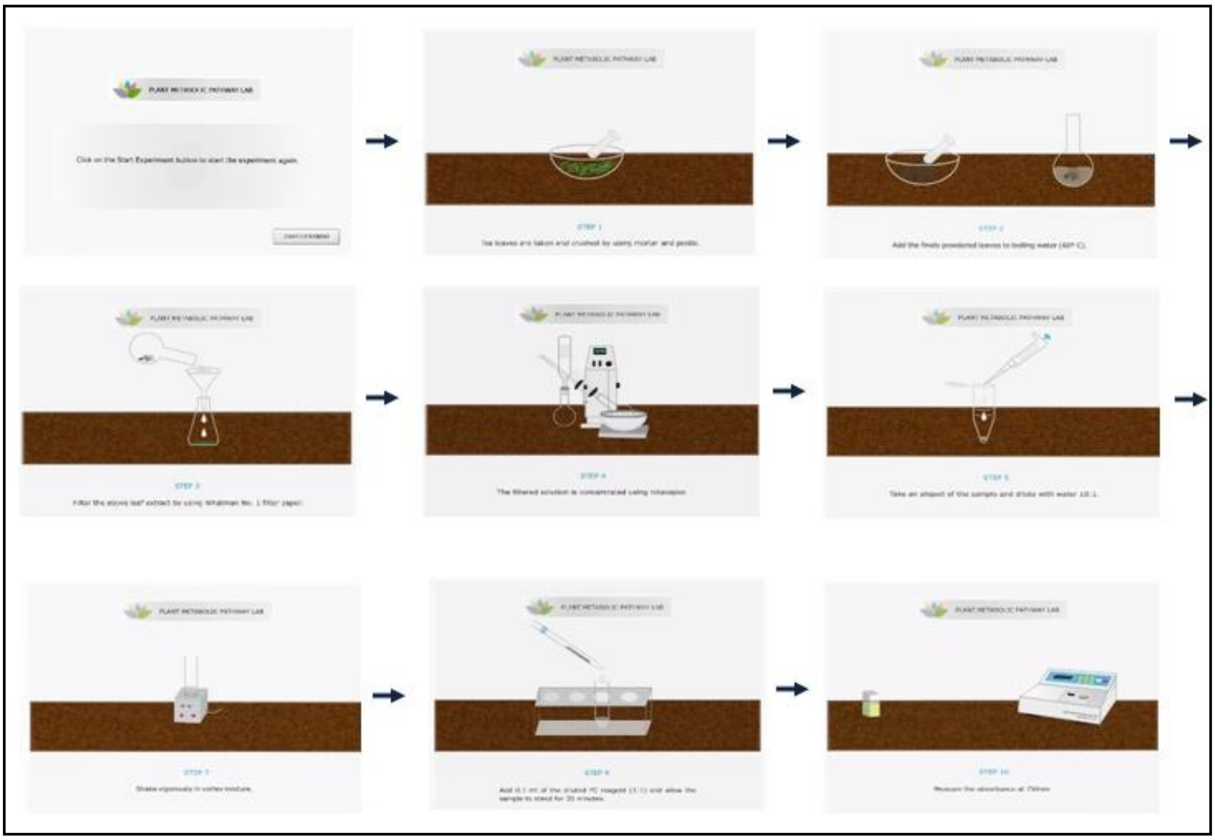

Figure 7. *Simulation based steps involved in extraction of flavonoids from Tea*

A remote view tab has been created which describes about the parts and functioning of a HPLC instrument. The remote labs may offer certain advantages such as;

- Repeating the experiments through learn and trial basis.
- Independent of time period to perform the experiment.
- Collaborative learning and gaining experience on the real equipment to operate.

The protocol for operating and connecting the instrument remotely in a stepwise manner is given under “Remote Trigger” tab. The details and the steps involved in connecting the HPLC instrument from outside location are represented in Fig 8.

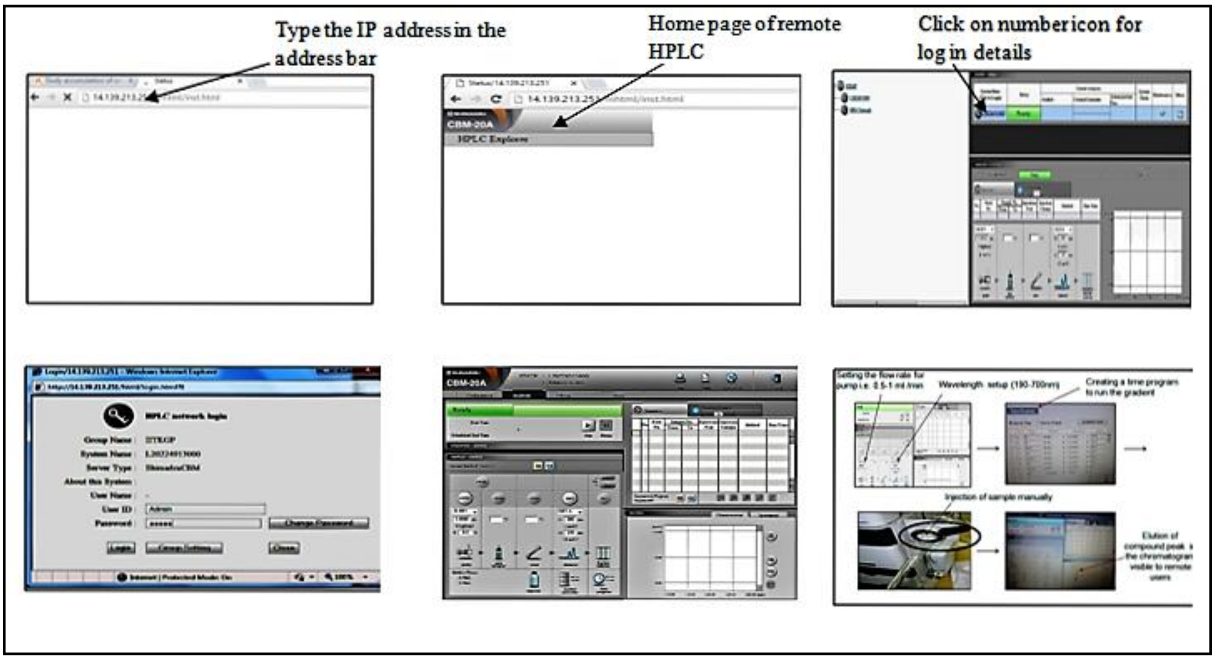

Figure 8. *A screenshot of the steps involved in the functioning of a HPLC instrument*

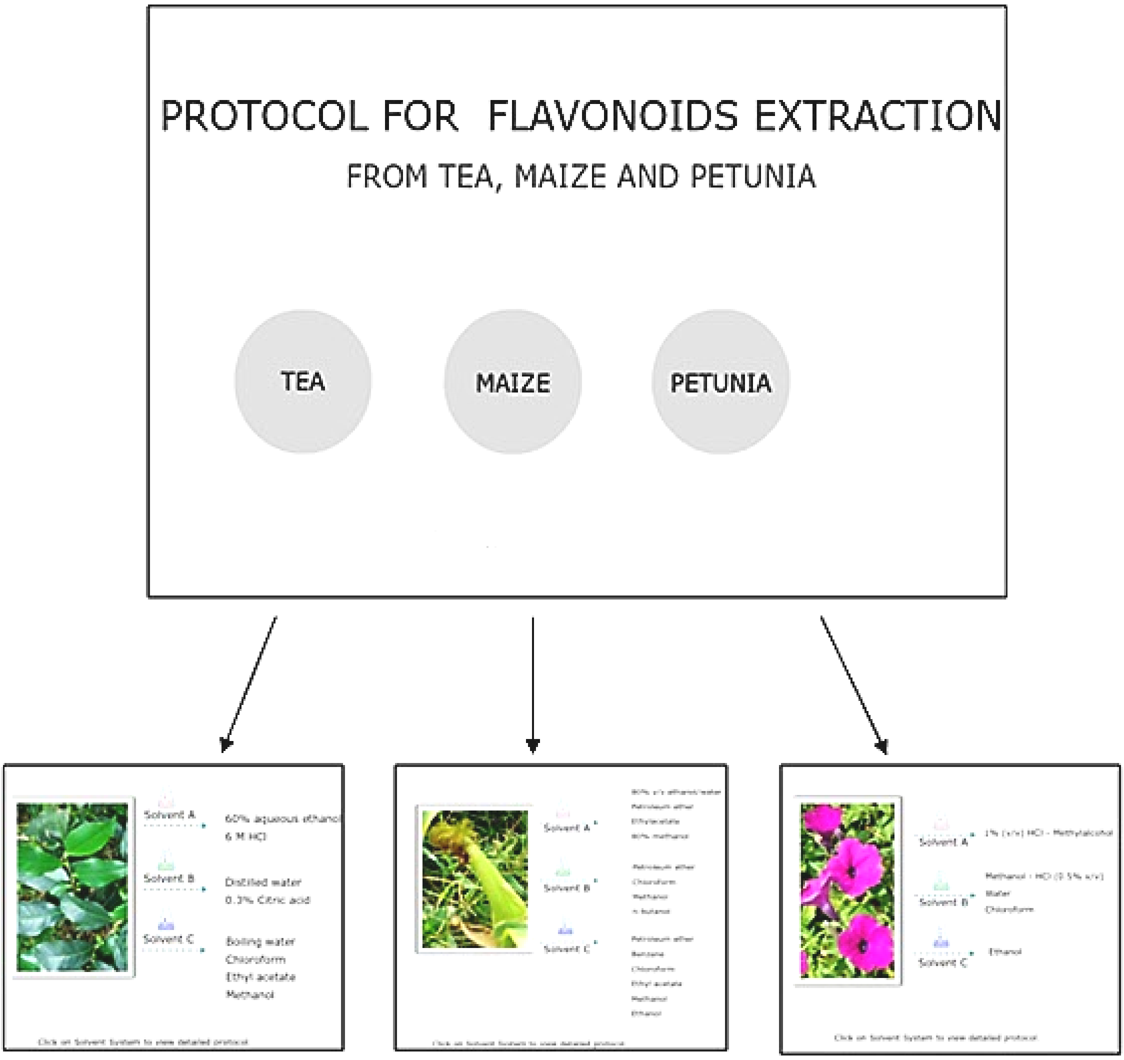

Figure 9. *Image of the homepage of solvent systems used for flavonoid extraction from the three plant model systems*

Another unique feature of our lab is about the versatility of the organic solvents used to isolate same type of flavonoids from same parts of the given plant system. An animation and simulation based protocols has been designed in such a fashion that a user will have several solvent systems specified for each plant. A home page is created for Tea, Maize and Petunia, in which he has the option of choosing a particular solvent system by clicking on it. When the user does that, then the webpage will be redirected towards the experimental steps involved for that particular chosen solvent system in a stepwise manner. So, he will be able to perform the same experiment in his conventional laboratory without much difficulty. Some researchers have suggested that science learning from simulations depends on peer collaboration as well as student to instructor discussion (Chou & Min, 2009). Fig 9 represents the selection of solvent systems used for extraction of flavonoids from the three plant models.

Therefore all the objectives designed will enable students to identify the accumulation pattern of flavonoids in plants, nature of complex pathways, suitable solvents used for extraction of flavonoids, role of mutants involved to enrich the functionality of flavonoids and solvent systems used for their extraction. The implementation of the virtual laboratories for secondary metabolites may provide the students and researchers an opportunity to gather the fundamentals underlying the experiment, its pre-visualization (videos, simulation) and data generation.

In order to check the validity and reliability of these labs and HPLC instrument, a group of students from our institute with vast experience and practical knowledge were selected. These students were not the same who involved in the virtual education of secondary metabolites from plant, so there was less chance of pre-test and post-test errors. It was kept in mind that both the group of students were provided with same teaching methods, content and practice time when required. Most important variables such as time and accuracy were considered. Time was measured in minutes and accuracy was based on the final result. Based on time taken and completion of experiments, student group outcomes (based on their analysis of individual samples of phenolics or flavonoids) were compared and standard error was calculated.

During designing of these labs, care was taken to avoid a number of possible validity threats that could arise during implementation. The most important of these was to make sure that affects of the result was dependent on the lab practice and prior student exposure. The simulation based protocols designed for each experiment allowed students to consider the concentrations of the reagents and weight of the plant tissue given and enabled them to undertake the experiment in their actual lab without any delay. These protocols helped them to overcome the standardization procedures which actually takes lot of time and effort.

Results obtained from virtual HPLC instrument and real instrument in the lab are comparable except at times when there is a need to close the experiment due to unavoidable circumstances. The study reveals that results obtained with same instrument in the actual lab are reliable and almost similar. Some of the validity threats that may affect the implementation of these labs were identified such as students from one group trying the experiment from another group, competition among themselves to finish the experiment on time and lack of interest or trying to quit the laboratory session before its completion. All these factors were taken into consideration and no students were allowed to change their groups during the time of experiment.

The students were able to do the qunatitative analysis of their samples through the peaks obtained from separated compounds in HPLC. The students had no such concerns with the virtual HPLC instrument and felt that they have the scope of making errors, which can be rectified through easy manipulations. The time provided to complete the sample analysis by HPLC experiemnt virtually was found to be sufficient. The results obtained from the questionnaire revealed that most of the students were interested in simulations made for extraction process, self evaluation and remote monitoring of the HPLC instrument. Students expressed that they don’t often get a chance to handle the HPLC instrument in their laboratories as it is very sophisticated instrument and should be performed under proper supervision with utmost care. The students during a brief interaction revealed that the simulations made for the experimental procedures and remote linking of the instrument has provided them a chance to learn the instrument manuals and priniples and to compare and interpretet their results by using our methods. The responses obtained from questionnaire show significant diversity in the way students explore and experienced the environment created for secondary metabolite study from plants through these virtual laboratories. The feedback obtained from the students indicates that the system provides a better mechanism in understanding the area related to the secondary metabolic pathways in plants. Based on the feedback of the students the findings were categorized into three different areas i.e. performance of the online remote experimentation, manuals created through simulations for doing experiments and the interpretation of the results obtained through virtual learning with their own findings in the lab. The findings of the tutorials and field study of our plant secondary metabolite virtual laboratory are represented in Fig 10.

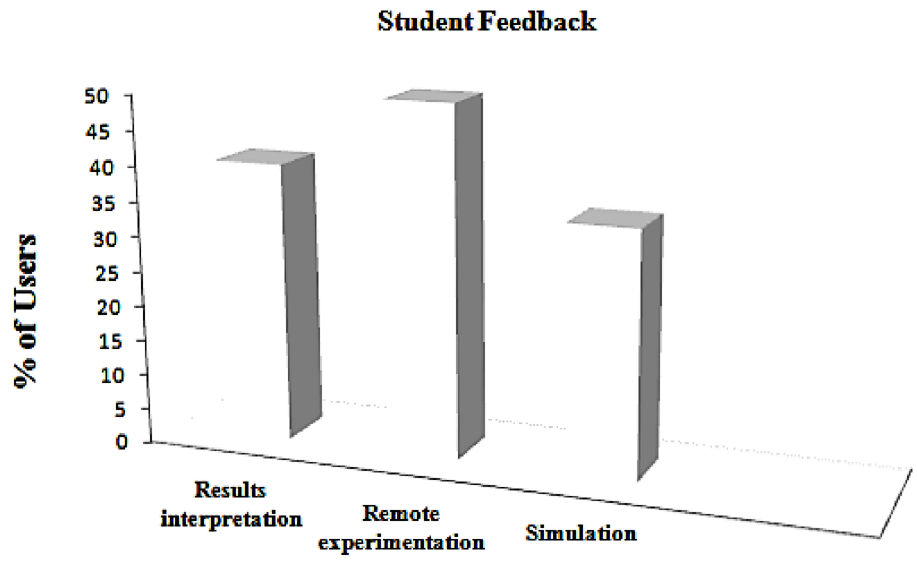

Figure 10. *Student feedback obtained from Plant Secondary Metabolite Pathway Virtual Laboratory*

Science subjects consist of majority of practical work. Using computer simulations like real laboratory eliminates the time required for equipment set up; reduces computation time and increases the accuracy and reliability of the results (Gandole, 2005). Students who used this tool provide in our labs suggested that these were helpful to prepare them for laboratory sessions before performing experiments in the actual laboratory. The approach towards implementing the remote and virtual lab in secondary metabolic pathways in plant is

a. Resource sharing becomes reality which improves the utilization of costly equipment.
b. Educational and Research material is intended for both students and professionals.
c. Interactive learning of the biochemical structures of the pathway.
d. Prevents the use of hazardous organic solvents and easy interpretation of the results.
e. Systematic study of flavonoids in a particular plant system from basic to advanced level.

Conclusion and Future Perspectives

The application of these remote laboratories and simulation based studies can be effectively used to teach science subjects in order to achieve fundamental understanding of the relevant area. Laboratory is an essential component of education which relates fundamental concepts to real world phenomena. Conventional laboratories need sufficient amount of space and complicated logistics for maintaining an appropriate learning environment. Although there are advantages with virtual laboratory as an educational tool but some areas are lacking which needs to be addressed. A virtual lab may never solve some of the complex issues comparable to real systems. Further all environmental parameters can't be virtualized thus allowing virtual lab to react different from a real one in rare cases. The study finding revealed that students shown curiosity to learn the concepts through computer based technologies. The experimental results provided by us were found to be correlated with their results obtained in the physical laboratory. One of the most interesting feature of these labs were appreciated by students was the data analysis. After the sample analysis in HPLC, students were able to see their results in the post run analysis and were able to calculate and interpretate the data with ease. They found value in both physical and virtual lab experience. These plant secondary metabolite pathway virtual laboratories had clearly made an impact on students' practical skills and understanding ability within a short period. Thus systematic and thorough evaluations of these new technologically enabled lab formats are needed before their applicability and the value can be understood and enhanced (Corter, Esche, Chassapis, Ma & Nickerson, 2011).

Future work includes study of some of the other classes of secondary metabolites from the given plant systems. Development of a user interface system for HPLC system is ongoing which allow remote user to book a slot for sample analysis. Further a multiple user interface for HPLC system is ongoing which will allow two-three users simultaneously to monitor and operate the instrument. The attempt made by the researchers will certainly ignite students' logical thinking and improve their practical skills regarding the secondary metabolism in plants and will serve as a useful educational tool.

Acknowledgements

The authors acknowledge the funding support from the Ministry of Human Resource and Development, New Delhi, Government of India.

References

Bonser, S.P., de Permentier, P., Green, J., Velan, G.M., Adam, P., & Kumar, R.K. (2013). Engaging students by emphasising botanical concepts over techniques: innovative practical exercises using virtual microscopy. *Journal of Biological Education*, *47* (2), 123–127.

Breakey, K.M., Levin, D., Miller, I., & Hentges, K.E. (2008). The use of scenario-based-learning interactive software to create custom virtual laboratory scenarios for teaching genetics. *Genetics*, *179* (3), 1151–1155.

Chou, S.W., & Min, H.T. (2009). The impact of media on collaborative learning in virtual settings: the perspective of social construction. *Computers & Education*, *52* (2), 417–431.

Corter, J.E., Esche, S.K., Chassapis, C., Ma, J., & Nickerson, J.V. (2011). Process and learning outcomes from remotely operated simulated and hands on student laboratories. *Computers & Education*, *57*, 2054-2067.

Diwakar, S., Parasuram, H., Medini, C., Raman, R., Nedungadi, P., Wiertelak, E., et al., (2014). Complementing Neurophysiology Education for Developing Countries via Cost Effective

Virtual Labs: Case Studies and Classroom Scenarios. *The Journal of Undergraduate Neuroscience Education*, *12*(2), A130-A139.

Domingues, L., Roch, I., Dourado, F., Alves, M., & Ferreira, E.C. (2010). Virtual laboratories in biochemical engineering education. *Education for Chemical Engineers*, 5, e22-e27.

Dormido, S., Esquembre, F., Farias, G., & Sanchez, J. (2005, December 10-15). Adding interactivity to existing Simulink models using Easy Java Simulations. Paper presented at the *44th IEEE European Conference on Decision and Control, and the European Control Conference*, Seville, Spain.

Duffy, J.L., & Mcdonald, J.B. (2008). Teaching and Learning with technology (3rd ed.). Boston: Pearson/Allyn & Bacon.

Gandole, Y.B. (2005). Changing the Nature of Undergraduate Electronics Science Practical Work. *International Journal of Instructional Technology and Distance Learning*, *2*(4), 1-14.

Gould, K.S., & Lister, C. (2006). Flavonoid Functions in Plants. In Andersen, O.M., & Markham, K.R. (Eds.), *Flavonoids- Chemistry and Applications* (pp. 397-425). CRC Taylor & Francis: Boca Raton.

Herga, N.R., Grmek, M.I., Dinevski, D. (2014). Virtual Laboratory as an element of visualization when teaching chemical contents in science class. *The Turkish Online Journal of Educational Technology*, *13* (4), 157-165.

Huang, C. (2004). Virtual labs: e-learning for tomorrow. *PLoS Biology*, *2* (6), 0734-0735.

Ma, J., & Nickerson, J.V. (2006). Hands-on simulated and remote laboratories: a comparative literature review. *ACM Surveys, 38* (3), 1-24.

Muhamada, M., Zaman, H.B. & Ahmad, A. (2012). Virtual Biology Laboratory (Vlab-Bio): Scenario-Based Learning Approach. *Procedia- Social and Behavioral Sciences*, *69*, 162-168.

Nair, B., Krishnan, R., Nizar, N., Radhamani, R., Rajan, K., Yoosef, A., et al., (2012). Role of ICT-enabled visualization-oriented virtual laboratories in Universities for enhancing biotechnology education- – VALUE initiative: Case study and impacts. *FormaMente*, Vol. VII, 1-2.

Nedic, Z., Machotka, J., & Nafalski, A. (November 5-8, 2003). Remote Laboratories versus Virtual and Remote Laboratories. Paper presented at the *33rd ASEE/IEEE Frontiers in Education Conference*, Colorado, United States.

Okojie, M.C., Olinzock, A.A., & Boulder, T.C.O. (2006). The pedagogy of technology integration. *The Journal of Technology Studies*, *32* (2), 66-77.

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Vladimir, M., et al., (2016). Virtual laboratories for education in science, technology and engineering: A Review. *Computers & Education*, *95*, 309-327.

Ray, S., Koshy, N.R., Reddy, P.J., & Srivastava, S. (2012). Virtual labs in proteomics: new E- learning tools. *Journal of Proteomics*, *75*, 2515-2525.

Scheckler, R.K. (2003). Virtual Labs, A substitute for traditional labs? *International Journal of Developmental Biology, 47*, (2/3), 231-236.

Soni, S., & Katkar, M.D. (2014). Survey paper on Virtual Labs for E-learners. *International Journal of Application or Innovation in Engineering and Management*, *3*(1), 108-110.

Waller, J.C., & Foster, N. (2000). Training via the web: a virtual instrument. *Computers & Education*, *35*, 161-167.

Weisman, D. (2010). Incorporating a Collaborative Web-Based Virtual Laboratory in an Undergraduate Bioinformatics Course. *Biochemistry and Molecular Biology Education*, *38* (1), 4–9.

Wen, F. (2012). Open Web-Based Virtual Lab for Experimental Enhanced Educational Environment. In P.Ghislandi (Eds.), *eLearning - Theories, Design, Software and Applications* (pp.227-248). Rijeka, Crotia, Intech.

Woodfield, B. F., Andrus, M. B., Andersen, T., Miller, J., Simmons, B., Stanger, R., et al., (2005). The Virtual Chem lab project: A realistic and sophisticated simulation of organic synthesis and organic qualitative analysis. *Journal of Chemical Education*, *82* (11), 1728–1735.