Journal of Information Technology and Application in Education (JITAE)

Developing a Collaborative Virtual Reality Learning System

[1]Hsiu-Mei Huang, [2]Shu-Sheng Liaw, [3]Yi-Chun Teng

[1]Department of Information Management, National Taichung University of Science and Technology, Taichung, Taiwan

[2]General Education Center,China Medical University, Taichung, Taiwan

[3]Institute of Information Science, Academia Sinica,Taipei, Taiwan

[1]hmhuang@nutc.edu.tw; [2]ssliaw@mail.cmu.edu.tw; [3]orz@iis.sinica.edu.tw

***Abstract*-The study attempts to build a collaborative virtual reality learning system (CVRLS) for medical education.The CVRLSwas designed by using Xj3D and was based upon the imagination, interaction and immersion features of virtual reality (VR) and the benefits of collaborative learning. With the cross-platform feature and networking resources supports from Xj3D, CVRLS establishes a multi-user,cross-platform collaborative virtual learning environment. Under this environment, learners and instructors are able to perform collaborative learning and engage in group discussions regardless of their locations and types of computer systems.**

Keywords-Collaborative Learning; Virtual Reality(VR); Human Anatomy

I. INTRODUCTION

The application of virtual reality technology has been gradually particularin medical education. Desktop virtual reality provides a low-cost alternative to build a virtual learning environment. Medical education with VR technology is beneficial to aid and optimize course instruction, since traditional medical use specimens,plastinate organs, or artificial anatomical models. Computer generated 3D models are reproduced virtually with quite low cost or no cost. These 3D organ models can aid instructors to teach and be distributed to every student via the Internet.

A lot of virtual reality learning systems have successfully deployed VR[1,2,3]. The Virtual Reality Laboratory of University of Michigan had built an interdisciplinary training system named Virtual Reality-Enhanced Medical Readiness Trainer [4]. The system integrated advanced technologies such as human patient simulators, immersive virtual reality CAVE systems, and video conferencing for the training of emergency personnel in a virtual reality learning environment. VR learning environment provides the simulation capacity to get inside of the 3D object significantly enhance instructional efficiency [3].

Immersion, imagination and interaction, are the three fundamental features of virtual reality [5]. Immersion refers to the sensory level experienced by a user in a virtual world. Hence, effective immersion serves as a tool in the communication process. Learners' immersion experience with the 3D VR learning environment creates a useful experience which will assist them to learn. Imagination allows learners to visualize concrete objects or abstract concepts in their minds by using virtual reality technology. Creative visualization is an important feature for virtual reality of helping learners to develop imagination in what learners want to learn in a virtual learning environment. The final feature of virtual reality is interactivity. The ability of providing highly interactive learning experiences is very important and valuable through a learner's input and responding to the new activity in the artificial reality instantaneous.

Vygotsky's zone of proximal development (ZPD) believed that learners' ability can be improved with adult guidance or in collaboration with more capable peer learners [6]. Within the collaborative learning environment, students can interact with each other, learn together and share their onions with peers. When learners work with teams, they make more valid judgments than working alone [7]. With collaborative learning, students develop mutual trust, develop cooperation and team working spirit and enhance relationship among peers. VR technologies enable more possibilities and provide cheaper and safer collaborative learning environments. However, the high cost of VR hardware equipments has been the barrier that keeps people from adopting it into collaborative learning system. Fortunately, with the new Web3D standard, VR multimedia data and user's control data can be easily transmitted over the Internet.

Much of collaborative learning strategy is built on VR technologies and allows learners to discuss and solve visualization problems in a group [1,2]. Especially, VR technology support special tools that help immersed learners work together are seen as having great potential for social scaffolding in collaborative learning [1]. The collaborative VR learning environment can be created as multiple users interacting within the same virtual space. The major benefit of collaborative learning environment is to increase interest among learners and improving critical thinking [8]. As a result, Tax'en and Naeve[2] suggested that educators may adapt their teaching style in collaborative virtual reality environments.

VR and collaborative learning applied to human anatomy draws learners' is very important for medical education while traditional course materials for human anatomy are mostly two dimensional,non-interactive and non-collaboratively. Building a collaborative learning system for human anatomy would bring the advantages of VR and collaborative learning into this field of medical education. A collaborative learning system, CVRLS, was designed by deploying virtual reality and network technologies in this study. This paper presents a collaborative virtual reality learning system (CVRLS) for medical education.

II. DEVELOPING CVRLS

The Internet supports the capacity of collaborative learning and effective communication infrastructures. Programming language and platform selection are important and critical technological considerations for CVRLS.

A. Technological Considerations

There was a brief survey on some virtual reality programming languages and tools for developing collaborative virtual reality learning environment. Table I lists these popular programming tools used for virtual reality, and their advantages and the characteristics were not suitable for this research[9].

TABLE IVRTOOLSCOMPARISON

Tools	**Advantage**	**Characteristics Not Suitable for This Research**
Second Life (SL)	• A large set of tools are available to users. Provides a library that contains rich set of objects, textures and scripts. These objects are readily applied or they can serve as templates where users can continue improving upon. • Allow fast and easy integrations. • Flexible, expandable. People can expand or update their community easily.	• A proprietary platform. Private servers require license fee. • Distractions. There are enormous types of communities in SL. Not all communities provide educational services. Learners may be distracted by communities that provide entertainment services and forgot their original goal. • SL has many participants and not all of them are good learners. Like a real society, pranksters and spams may happen. • Viewer is relatively large.
Paper-Vision3D/ Flex / Action Script	• Flash player has the most penetration rate. • Backward compatibility and easy integration. Flash application can integrate or be integrated with existing or old Flash/HTML learning systems. • Good multimedia support. • Relatively easier to implement than C++/Java.	• Limited support of 3D graphic acceleration, resulting in a very poor performance. We can't put too many objects in a scene. • Serious memory leaking problems exist. • Relatively poor rendering quality..
OpenGL/ DirectX / C++	• Well supported by 3D graphic accelerator. • Efficient graphic rendering pipeline. • Programmers have the most control over the program. Programmers can create their own effects, filters, special animations and all other tricks. • DirectX with rich multimedia, networking and I/O support.	• OpenGL with no native sound or network support. • Relatively difficult to code. • DirectX is a proprietary platform. System developed with DirectX may have issues running under Non-Windows OS.
Xj3D/ Java	• Native network support. • Cross-platform. • Free development tools and libraries. • Relatively small plug-in (viewer). • Extendibility. • Animation (routers as it is called in X3D) libraries and templates are available to serve various kinds of needs. • Easy to implement multi-threading.	• Native mesh data compression is NOT supported. In fact, the standard mesh file stored by using XML is even bigger than other uncompressed format such as SMF or PLY.
Virtools	• Relatively simple to build. • Source project is more intuitive to understand. Virtool project components are graphical as oppose to texts in C++/Java. • Less programming skills required. • Provides project preview functionality. Programmers can see scenes or effects immediately.	• Relatively low control over the application. Programmers may only use built-in components. Custom scripts are possible but doing so loses the advantage of simple-to-build. • A proprietary platform. Limited resources. Also, only Windows and MacOS are currently supported. • External plug-in needed. • Development software is expensive.

X3D is an open standard resource for real-time 3D communication [10]. Xj3D provides X3D toolkit and programming library based on Java [11]. Therefore, Java-based Xj3D was applied in the platform for this study because of the advantages of good network support and cross-platform.The system uses Xj3D library and scene access interface (SAI, the programming interface to Xj3D library) to manipulate and render 3D scene. CVRLS connects to other instances through Java networking API. In addition, the system accesses X3D models through Xj3D browser, which is embedded in CVRLS.

B. Architecture and Implementation

To allow dynamic course content, the CVRLS system is a Java-based program. The CVRLS core program consists of CVRLS main class and function libraries. The main class calls Xj3D browser to access X3D-format model files. CVRLS connects to other instances through Java networking API. The data structure adopted by CVRLS adheres to the scene graph standard defined in X3D. Such data structure is object-oriented and exhibits advantages that appear in OOP. In particular, data control, data transmission, 3D object rendering and animation hierarchy can be performed and handled efficiently.

1) Scene Graph:

Scene graph is the standard data structure in X3D. The constituting component of scene graph is called node. A node is analogous to an object instance in object-oriented programming (OOP). In CVRLS, a node is a basic building object such as a plane, a sphere or a control button. Similar to object in OOP, a node can be reused and it may have several properties. Property of a node is called field. In the system, fields are used to describe node's shape, color, material, text and associated animation.

A scene graph organizes different nodes into tree structures. A tree structure is very useful in representing inheritance relationships between each node. Any operation applied on parent nodes will also be applied on their child nodes. For example, when we transform and rotate a node, all of its child nodes will be transformed and rotated. However, any action done on child nodes will not affect their parent nodes.Such characteristic is very useful when we group nodes. Relationships between each node are simpler and clearer.

2) Router:

A scene graph organizes nodes and their inheritance relationships. However, a scene graph cannot provide information about execution order and logical relationships between each node. Hence, routers are used to complement these deficiencies of scene graph. In addition, routers enable inter-node data communications. Coordinate data of control points are then sent to object node via inter-node communication. That piece of bone can thereafter move along the moving path.

3) Communication:

The system employs client and server architecture for data communication. A CVRLS server is responsible for receiving client actions and broadcasting processed information back to all clients. At any point of time, only one user is permitted to control the models. Others can observe actions made by the controller on their own computer screen. Controllers are appointed by server.

4) Separated Program Core:

CVRLS is designed such that controls over 3D objects (mostly organs), course contents and all course-related functionalities are separated from program core. Program core provides and supports instructions dictated by the X3D scripts embedded in X3D files which are to be loaded. Such design has two advantages. The first advantage is that non-system errors are easier to debug, as methods in the program core are kept from doing course-specific tasks. The second advantage is that course content can be changed.

C. Implementations

The core program of the system is written in Java. The CVRLS core uses Xj3D library and scene access interface (SAI, the programming interface to Xj3D library) to load, parse, manipulate and render 3D scenes. Scenes and their containing objects in turn have associated X3D scripts which describe animations, transparencies, geometry properties, shading properties, and some other effects. In summary, we wrote Java programs to provide and support instructions dictated by the X3D scripts.

1) User Interface:

The main user interface is based on the Xj3D browser. In addition to basic built-in components, we added functionalities that provide various interactive controls and the capability to display web pages. This modified Xj3D browser is instantiated and accessed through methods provided by the Xj3D library. Input data is captured by the modified Xj3D browser and then delivered back to CVRLS core.

2) Networking:

The system employs client and server model. CVRLS relies on TCP transmissions to deliver and receive geometry information, control data and synchronization data. To effectively utilize system resources, CVRLS adopts the concept of concurrent programming.

3) Synchronization:

Synchronization is required in order to have all learners have real-time interactions. A CVRLS server receives 3D model geometry information and geometry control data from controller. This server also gets input texts and system control data from individual clients. Synchronization data, along with other processed data, are then broadcasted back to all clients.The synchronization process of geometry information is depicted in Fig.1.

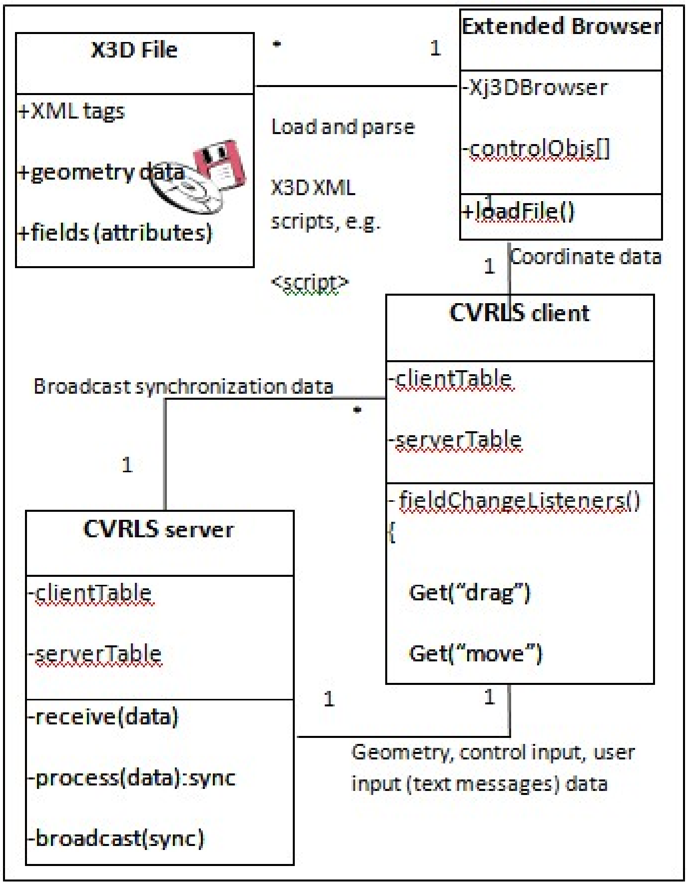


Fig. 1Simplified model diagram for synchronization process

III. RESULTS

The final system implemented provides learners with interactive controls over 3D models, images and texts. Learners construct new knowledge by observing 3D organ models from various perspectives, assembling organs to proper locations and reading instructional web pages.

A. Functionalities and Features

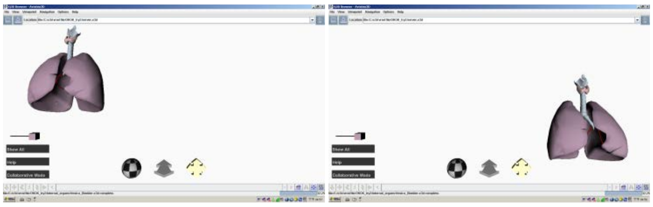
The system provides learners with interactive controls over rich 3D models, images and texts. Learners construct new knowledge by observing 3D organ models from various perspectives, assembling organs to proper locations and reading instructional web pages. CVRLS provides two operating modes. The first mode is single user self-learning mode. In this mode, individual learners interact with 3D organs and read course web pages. The main user interface of CVRLS is a 3D model browser that provides various interactive controls. Through simple mouse drag and click, users can transform, zoom and rotate 3D organ models. In addition, CVRLS allows users to adjust transparencies of individual organs. With these features, users can view any organ from any perspective, even from a perspective where other organs block the view. An instructional webpage is associated with each organ. Users can click an organ to open up the webpage and read the descriptions.

To provide collaborative learning environment, multiple instances of CVRLS communicate to each other via network. CVRLS employs client and server architecture. A CVRLS server receives 3D model geometry information, user input data and user control data from individual clients. Synchronization data, along with other processed data, are then broadcasted back to all clients. At any point of time, only one user is permitted to control the models. Others can observe actions made by the controller on their own computer screen. Controllers are appointed by server.

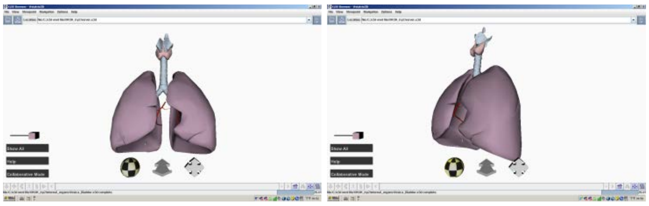
An instant conversation platform is provided for users to discuss, express opinions or ask questions. Server maintains participant list. Human organs are randomly placed. The sub window on the upper left corner is the instant conversation window. Movements of all 3D models are synchronized. Learners observe actions made by the controller on their own computer screen.

B. Screenshots for Functions

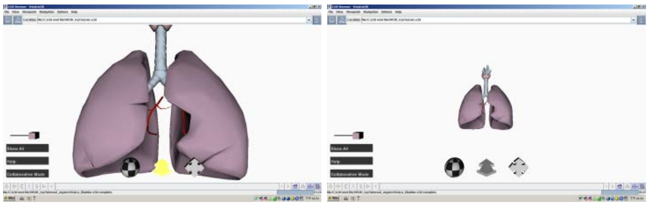
Through simple mouse drag and click, learners can transform, zoom and rotate 3D organ models, as shown in Fig.2.



a Translate an organ model



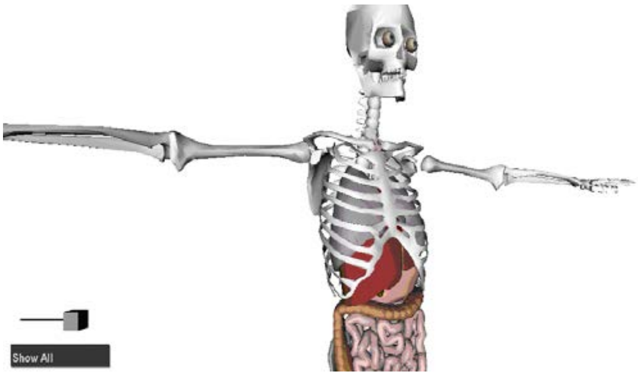
b Rotate an organ model



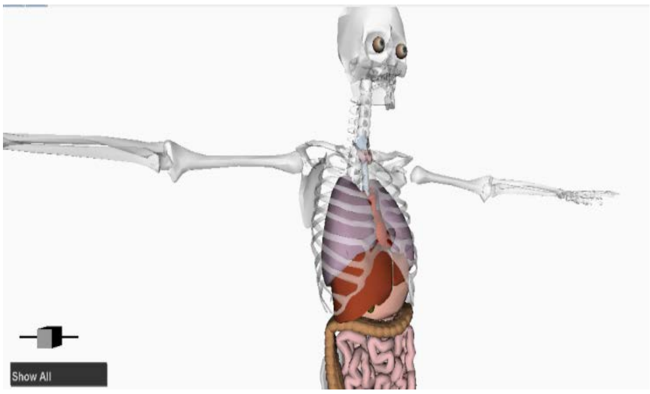
c Zoom in an organ model

Fig. 2 Learners interact with 3D models

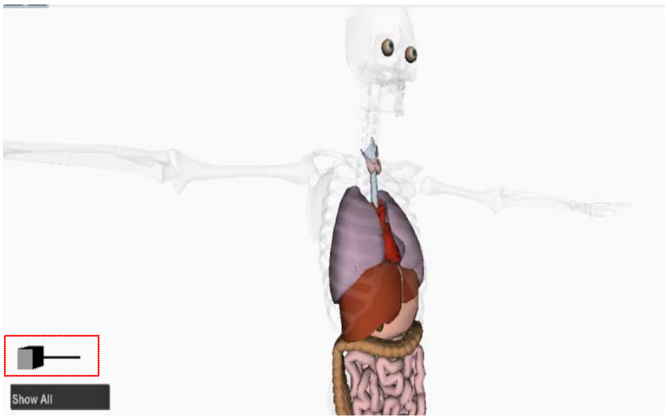
CVRLS allows learners to adjust transparencies of individual organs. With these functionalities, learners can view any organ from any perspective, even from a perspective where other organs block the view. This functionality is demonstrated in Fig.3.



a.Original skeleton



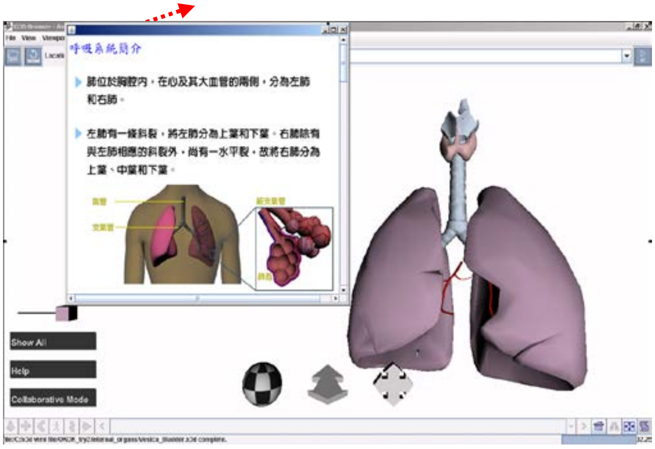
b.Skeleton is adjusted to be semi-transparent



c.Skeleton is adjusted to be almost transparent

Fig. 3 Adjust transparencies (The slider inside the red dashed box controls the transparency of the selected organ)

An instructional webpage is associated with each organ. Users can click an organ to open up the webpage and read the course contents as shown in Fig.4.


Respiratory System

呼吸系統簡介

肺位於胸腔內，在心及其大血管的兩側，分為左肺和右肺。

左肺有一條斜裂，將左肺分為上葉和下葉。右肺除有與左肺相應的斜裂外，尚有一水平裂，故將右肺分為上葉、中葉和下葉。

Fig. 4 Screenshot of lung model and instruction webpage

The initial screen displays randomly scattered human organs. The instructor may demonstrate organ assembly to learners or appoint a learner to do practices. For example, the person in control drags human organs to their appropriate locations to reconstruct a complete human body. Others observe actions made by the controller on their own computer screen. This process is depicted in Figs. 5 and 6. Moreover, an instant conversation platform is available for learners to discuss, express opinions or ask questions as shown in Fig. 7.

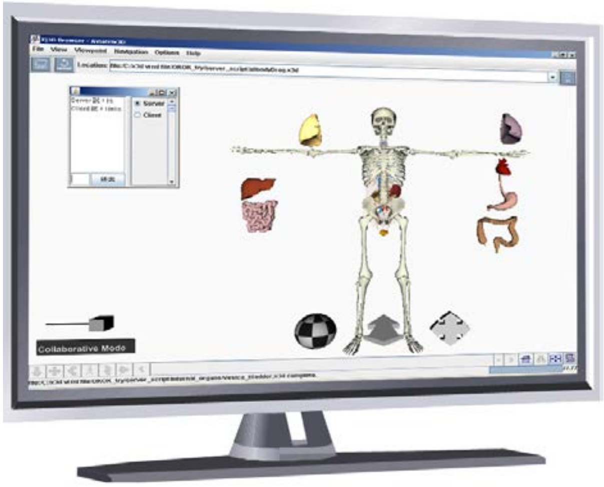


Fig. 5 The student in control drags organ to proper place

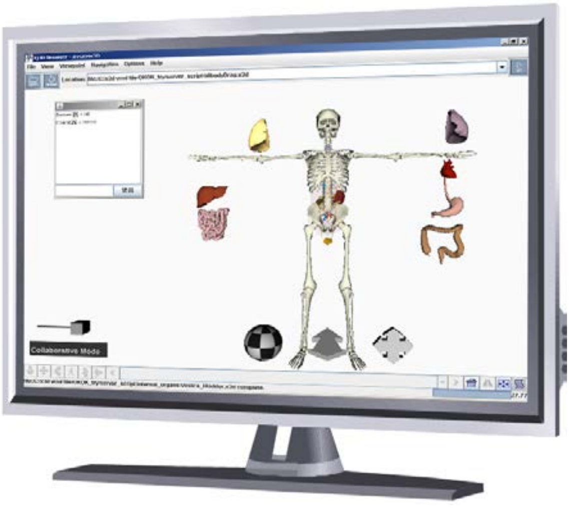
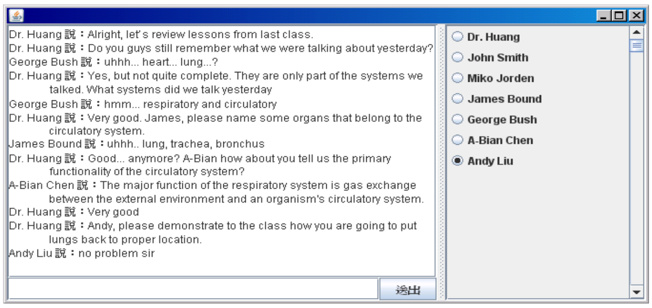


Fig. 6 Movements of all 3D models are synchronized. Actions done by the controller are displayed in all other users' screens



Dr. Huang 說：Alright, let's review lessons from last class.
Dr. Huang 說：Do you guys still remember what we were talking about yesterday?
George Bush 說：uhhh... heart... lung...?
Dr. Huang 說：Yes, but not quite complete. They are only part of the systems we talked. What systems did we talk yesterday
George Bush 說：hmm... respiratory and circulatory
Dr. Huang 說：Very good. James, please name some organs that belong to the circulatory system.
James Bound 說：uhhh.. lung, trachea, bronchus
Dr. Huang 說：Good... anymore? A-Bian how about you tell us the primary functionality of the circulatory system?
A-Bian Chen 說：The major function of the respiratory system is gas exchange between the external environment and an organism's circulatory system.
Dr. Huang 說：Very good
Dr. Huang 說：Andy, please demonstrate to the class how you are going to put lungs back to proper location.
Andy Liu 說：no problem sir

○ Dr. Huang
○ John Smith
○ Miko Jorden
○ James Bound
○ George Bush
○ A-Bian Chen
● Andy Liu

Fig. 7 Instant conversation platform: instructor and learners discuss questions

C. Discussion

Overall, learners had positive attitudes towards CVRLS. Majority of participants perceived that CVRLS had improved their learning efficiency. The results indicate that the three features of VR (interaction, imagination, immersion) and collaborative learning are beneficially developed in CVRLS. This software has the advantages of low development cost, cross-platform, low system requirement and high expandability.

CVRLS provides infrastructures and functionalities to support collaborative learning successfully. With synchronized learning materials, instructors are able to monitor the status of every student. Instructors are hence able to ensure that assigned member responsibilities are fulfilled and that members interact and help each other accomplish the task and promote each other's success. This is very helpful to establish positive interdependence and individual accountability.

Through the ability of responsibility assignment, instructors are able to allocate different tasks to each student. Individual students will have the opportunities to try every role and practice the skills they most lack of. Students can take turns to enhance their leadership, decision-making, trust-building, communication, and conflict-management skills. Ultimately teamwork skills will be developed.

Finally, the communication platform enables group discussions which are crucial for effective group processing. On the other hand, instructor's efforts are necessary in addition to software system's capabilities. Instructors need to ensure that team members engage in effective discussions and how well students are achieving preset deliverables and maintaining effective team relationships. Future enhancements of CVRLS may include more organ models, interactive video descriptions, and instant quiz. On the other hand, we believe that it will also be beneficial to apply VR technologies to the education of other disciplines.

ACKNOWLEDGEMENTS

The authors appreciate Ming-Cong Peng for assisting the system design and data collections. This study was supported by NSC100-2511-S-025-003-MY3.

REFERENCES

[1] W. R. Sherman, and A. B. Craig, "Understanding Virtual Reality", New York: Morgan Kaufmann Publishers,2003.

[2] G. Tax'en, and A.Naeve, "A system for exploring open issues in VR-based education", Computers & Graphics, vol.26, pp.593–598,2002.

[3] A.J. Levinson, B.Weaver, S. Garside, H.McGinn, and G.R. Norman," Virtual reality and brain anatomy: a randomised trial of e-learning instructional designs," Medical Education, vol.41,no.5,pp.495-501, 2007.

[4] UM-VRL: Medical Readiness Trainer – MRT [Internet]. "Virtual Reality Laboratory at the University of Michigan," Available from: http://www-vrl.umich.edu/mrt/index.html,[cited 2012 Feb. 10].

[5] G.C .Burdea,andP.Coiffet ,"Virtual Reality Technology". 2nd ed. New York: John Wiley & Sons; 2003.

[6] L. S. Vygotsky," Mind in society", Cambridge. MA:Harvard University Press,1978.

[7] M.LJ. Abercrombie,"Aims and Techniques of Group Teaching", England: Society for Research into Higher Education, 1970.

[8] K. Dimitropoulos, A. Manitsaris, and I.Mavridis, Building Virtual Reality Environments for Distance Education on the Web: A Case Study in Medical Education", International Journal of Social Sciences,vol. 2, no. 1,pp. 62-70, 2008.

[9] H.M. Huang, S.S Liaw,W.T. Chen,Y.C. Teng**,** "Building an Interactive Role-Playing Learning System for Medical Education",E-Learn 2009, Vancouver, Canada, October 26-30, 2009.

[10] Web3D Consortium [Internet],"California: The Web3D Consortium", Available from: http://www.web3d.org/,[cited 2012 Feb. 13].

[11] Xj3D - Java based X3D Toolkit and X3D Browser [Internet]. "California: The Web3D Consortium", Available from: http://www.web3d.org/x3d/xj3d/,[cited 2012 Feb. 13].

Hsiu-Mei Huang is a Professor at the National Taichung University of Science and Technology in Taiwan. She obtained her Ed.D. in Instructional Technology of Education at Seattle Pacific University, Seattle, U.S.A. She received her M.S. degree in Applied Mathematics from National Chung HsingUnversity, and B.S. degree in Computer Science from Soochow University in Taiwan.Dr. Huang's research interests are in e-learning, electronic commerce, and Virtual Reality learning. Her works has appeared in Journals such as *Computers & Education, British Journal of Educational Technology, Computers in Human Behaviors, Educational Technology, International Journal of Instructional Media, Information Systems Management, and Pattern Recognition*.

Shu-Sheng Liaw is Professor at the China Medical University, Taiwan. His current research interests include e-learning, mobile learning, attitudes investigation of technology acceptance, knowledge management, and Virtual Reality for learning. He is in the editorial board of International Journal of Learning Technology and International Journal of Society System Science. His research has been published in British Journal of Educational Technology, Computers & Education, Computers in Human Behaviour, Educational Technology, Information Systems Management, International Journal of Instructional Media, Journal of Computer Assisted Learning, Perceptual and Motor Skills, and Psychological Report.

Yi-Chun Teng is a research assistant at the institute of information science, Academia Sinica. He obtained his BSc degree at the School of Computer Science, Simon Fraser University and earned MS degree from the College of Engineering and Computer Science, California State University, Fullerton. Yi-Chun has participated in E-learning and VR-learning researches in National Taichung University of Science and Technology. His current work in Academia Sinica includes Android programming and Java web service programming.