2017 IEEE Third International Conference on Multimedia Big Data

Experiences with Multi-Modal Collaborative Virtual Laboratory (MMCVL)

(Invited Paper)

Kevin Desai, Rong Jin,
Balakrishnan Prabhakaran, Paul Diehl
The University of Texas at Dallas
Richardson, TX, USA
{Kevin.Desai, Rong.Jin, bprabhakaran, pdiehl}@utdallas.edu

Uriel Haile Hernndez Belmonte,
Victor Ayala Ramirez
Universidad de Guanajuato
Guanajuato, Gto., Mexico
{hailehb, ayalav}@laviria.org

Vinu Johnson, Murry Gans
Eastfield College
Mesquite, TX, USA
{vinujohnson, mgans}@dcccd.edu

***Abstract*—Training through Multi-modal Collaborative Virtual Laboratory (MMCVL) aims at developing or improving skills of students without the need of them being physically present. MMCVL addresses the problems faced by the current education system such as lack of resources and safe use of expensive laboratory equipment. It also provides a means for easy collaboration between students and teachers from different universities and schools. Multimedia data in terms of 3D mesh, skeleton, audio and virtual object physics interaction are incorporated in MMCVL to provide a 3D Tele-Immersion environment.**

The system uses low-cost RGB-D cameras such as Microsoft Kinect V2 to capture and generate 3D model of the person by extracting him/her from the entire captured data and immersing it in different interactive virtual environments. Different lab environments can be virtually created to provide for and replace the real laboratories. Object interactions allow for users to interact with the virtual objects present in the scene similar to real lab setup. Recording module of the toolkit allows future reference for training and testing of the student. The system also facilitates virtual feedback by giving the correct measurements, video demonstrations as well as audio communication with the collaborating teacher. Two different Chemistry experiments were performed to evaluate the user experience and usability aspects of MMCVL. Results obtained from the user study analysis prove the system to be fun and realistic, and at the same time engaging and motivating for learning laboratory experiments.

***Keywords*-Virtual training, Mixed/Augmented reality, Interactive learning environments, 3D Tele-Immersion**

I. Introduction

Producing sufficient numbers of graduates who are prepared for science, technology, engineering, and mathematics (STEM) occupations has become a national priority in the United States. To attain this goal, some policymakers have targeted reducing STEM attrition in college, arguing that retaining more students in STEM fields in college is a low-cost, fast way to produce the STEM professionals that the nation needs [1]. Such preparation for STEM education needs to be fostered initially in K-12 schools and community colleges so that the students can successfully transition to and complete a 4-year degree in STEM disciplines. Unfortunately, this often does not occur and attrition is a serious problem. Reasons for the inadequate training [1] include lack of resources (such as well-equipped laboratories and qualified teachers) as well as lack of creative ways in which STEM subjects are taught.

Virtual laboratories first address the lack of laboratory infrastructure in most high schools and community colleges, especially in areas with low socioeconomic status [2]. In place of hands-on laboratories, virtual ones replace the need for most physical space and do so without the associated cost of buildings, equipment, materials, and maintenance. This opens up a wide array of experiments to audiences that would otherwise not be able to undertake them. Virtual laboratories also permit the partnerships of leading universities and their faculty with instructors in high schools, e.g., training sessions and summer workshops enhance the skill sets of the latter and facilitate the use of sophisticated experimental protocols. Pedagogical advantages to virtual laboratories include enabling investigation of non-observable phenomena, allowing multiple trials in narrow time frames, and providing online adaptive prompts and directions, among others [3] and [4]. Virtual laboratories are also consistent with changing norms and learning preferences for millennial generation students accustomed to multimedia interactions [4], [5]. Beyond redressing the problems that inhibit the supply of STEM graduates, the system has a number of other distinct advantages. First, by focusing on community college and ultimately high school education, the application of virtual laboratories reaches and hopefully encourages several underrepresented populations in STEM career fields. Minority students disproportionately begin post-secondary education in community college settings [6], [7]. In addition, non-traditional students can have access to laboratory experiences that would otherwise not be easily available for those who have significant employment and family obligations. Second, virtual laboratories offer substantial safety advantages over hands-on settings in fields in which dangerous chemicals and processes are involved. Third, by incorporating the concept of remote collaboration, the teacher can be physically absent but still participate in the session and monitor the student's progress remotely.

978-1-5090-6549-3/17 $31.00 © 2017 IEEE
DOI 10.1109/BigMM.2017.62

A. Rationale

Previous studies [4], [5] have shown that virtual laboratories represent the changing norms and learning preferences for millennial generation students accustomed to multimedia interactions. MMCVL takes the concept of virtual laboratories many steps further by:

- Leveraging on collaborations in the virtual laboratory world that enhances the learning experience by allowing students to work with their remote peers (i.e., students participating in the virtual world from different places). It allows teachers to work with remote students on a more personal level.
- Allowing expensive equipment such as robots to be used in a safe manner both for students and for the equipment.

MMCVL-based experiments are relevant not only for specific STEM majors, but also for non-majors.

B. Proposed System

The main goal of this paper is an innovative paradigm of multimodal, collaborative virtual laboratory (MMCVL) that would facilitate: (i) running virtual experiments pertaining to different STEM disciplines; (ii) remote access to qualified faculty and appropriate resources; (iii) work with a cohort group of students to promote collaborative learning.

The proposed architecture uses Microsoft Kinect V2 [8], a low-cost and off the shelf depth sensing, non-invasive, markerless camera, to capture the entire scene in real-time. Apart from RGB and depth streams, Kinect V2 also provides a skeletal stream that provides the movements of the human body joints' movements in 3D space. This skeletal data stream is used to perform physically based interactions. The captured 3D human model is placed into an AR scene for collaborative virtual laboratory. Based on this approach, a toolkit consisting of 2 Chemistry Lab Experiments is made available for virtual training. The toolkit also contains additional modules for personal information storing, 3D session recording and playback (for future reference and testing), and virtual feedback through the system.

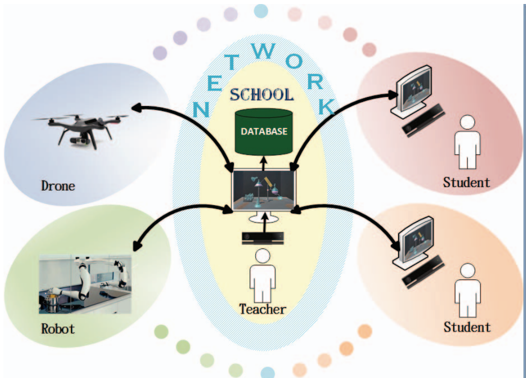
C. Contribution

In this paper, we contribute by sharing our experiences in using a multi-modal, collaborative augmented virtuality environment for STEM education. This environment, named MMCVL, exchanges voluminous multi-modal data over high-speed networks with low latency for facilitating collaboration among the participants. MMCVL can provide real-time feedback, if the experiments are not done in a proper manner and it can also be programmed to grade laboratory assignments. MMCVL has a database backend for storing the laboratory sessions to serve as a digital record. Though the proposed MMCVL system has been initially tried out as a chemistry laboratory, it can function as physics, biology or a robotics laboratory by suitably modifying the virtual environment.

II. Related Work

There have been several efforts in incorporating virtual laboratories in STEM education [9], [10], [11], [12]. [9] describes the effect of virtual chemistry experiments in students' achievement, demonstrating that the developed virtual chemistry laboratory software was at least as effective as the real laboratory - in terms of students' performance in the experiments and students' ability to recognize laboratory equipment. [10] provides an excellent survey of research efforts in virtual experimentation and its comparison with the physical or real laboratory based ones. The authors of this research created a new methodology to study this comparison - Virtual and Physical Experimentation Questionnaire (VPEQ). Using VPEQ, authors came up with new scales of Usefulness of Lab, and Equipment Usability that measured attitudinal dimensions in virtual and physical lab experiences. Experienced and novice users in virtual performances were compared in [13]. The study shows that previous experience in a different scenario prepared students to transfer inquiry skills to a new one. The concept of virtual learning in STEM education is not just limited to the academic research but has also captured the attention of the technical industry [14]. Lifeliqe [15] has designed one such VR-based application that provides 3D models for STEM and interactive 3D lesson, and plans to empower deep learning in K-12 STEM. VR-based STEM labs provided by zSpace [16] help students to better understand and retain the difficult and abstract concepts. Immersive VR Education [17] has created Lecture VR that simulates a lecture hall in virtual reality with the capability to add effects that cannot be provided in a traditional classroom settings.

Multi-media data captured in such fashion are also used in various other applications such as interactive gaming, remote training, entertainment, rehabilitation, etc. [18] shows different games generated using such a system for the purpose of exercising. It showcases the integration of the MM data into different virtual environments. Due to the complexity of such systems, various challenges related to data acquisition, transmission and rendering need to be addressed. [19] shows that a single frame captured using RGB-D camera (Kinect V2) generates more than 20000 points. A single camera site contains about $0.5MB$ of depth and $2MB$ of color information. Transmitting $2.5MB$ at $10fps$ requires a network bandwidth of $> 150Mbps$. [19] addresses this problem of high bandwidth by reducing the data size using visual quality based vertex selection approach. It adapts to the available bandwidth and generates a sparse representation of the object. The compression of 3D and RGB information to about 90% is attained without noticeable visual quality degradation.



(a)

(b)

Figure 1: (a) Possible Uses of Multimodal Collaborative Virtual Laboratory (MMCVL) (b) Avatars of Student and Teacher in Different Locations Transported over MMCVL to collaborate in the same Virtual Space Representing a Chemistry Laboratory

III. Proposed MMCVL System

MMCVL is a collaborative, 3D immersive software infrastructure functioning over a network of computers (desktops/laptops), 3D (or RGB-D) cameras, haptic devices, and 3D display. A small group of students (3 or 4) can explore in real-time, the virtual environments produced by this test-bed in a collaborative manner. Figure 1 shows a virtual chemistry laboratory where a teacher can demonstrate experiments to a remote student. Here, avatars of teacher and student captured by 3D cameras are put in the same virtual space that acts as a STEM laboratory. MMCVL uses Tele-Immersion Gaming Environment and Resources (TIGER). A 3D immersive tele-rehabilitation scenario, involving 3D camera and haptic device on both the patient and the therapist side, has been developed over the TIGER framework [20]. This system was widely reported by the news media in the USA, based on the front-page article in Austin American Statesman [21]. (A video demonstration of a two-player soccer penalty game developed over TIGER is shown in [22].)

One can easily visualize the advantages of such a virtual laboratory. It can help train students (and teaching assistants) to use the virtual hazardous substances before actually working with real ones. For instance, similar to a virtual chemistry lab, we can visualize a virtual biology lab, training students to work with (virtual) potentially harmful pathogens. By changing the virtual environments, we will be able to emulate experiments for different STEM disciplines, while reusing the same physical infrastructure and provide a cost-effective time-sharing of precious resources (equipment, classrooms, desktop/laptops, servers, data network, etc.). An appropriate example for handling expensive resources is the use of MMCVL to operate equipment such as robots and drones, Figure 1a. Gesture-based interactions can be programmed and tested using MMCVL before operating expensive robots.

Using MMCVL based STEM experiments, we address the following open questions: (1) How do student-learning outcomes compare between collaborative virtual reality labs and in-person labs in STEM classes at the community college? (2) Do learning outcomes of virtual reality labs predict success in future in-person labs for students in science classes at the community college? (3) What impact does participation in virtual reality labs in science classes at the community college have on students? MMCVL enhances the state-of-the art virtual labs by incorporating two important new additional characteristics in virtual experimentation: (i) collaboration with teacher and peer students; (ii) operation of expensive equipment, such as robots, in a safe manner.

A. MMCVL Architecture

MMCVL incorporates multiple modalities: human body skeleton, RGB, depth, audio and virtual objects. Figure 2 outlines the flow and steps involved in MMCVL. The RGB, depth and skeleton data streams obtained from 3D cameras such as Microsoft Kinect v2 are used to generate the 3D model of the person. The RGB and depth information are used to obtain a 3D point cloud representation of the entire scene. Skeleton data is used to segment and extract the person from the complete 3D scene point cloud using Voronoi-based segmentation, as shown in [23]. Since the RGB-D cameras such as Kinect use time of flight capturing technology, there are lot many noisy points. Median filter and depth based filter is used to clean the 3D point cloud, removing the edge noise. The clean 3D point cloud of the extracted person is triangulated using dense meshing strategy [24] to obtain the mesh representation. The sparse mesh is generated from the same by removing some points and triangles based on the curvature information [19]. The texture information pertaining to the person is extracted from the RGB image obtained using the skeleton and 3D point cloud of the person. The extracted texture information is laid over the mesh generated to obtain the final 3D mesh of the

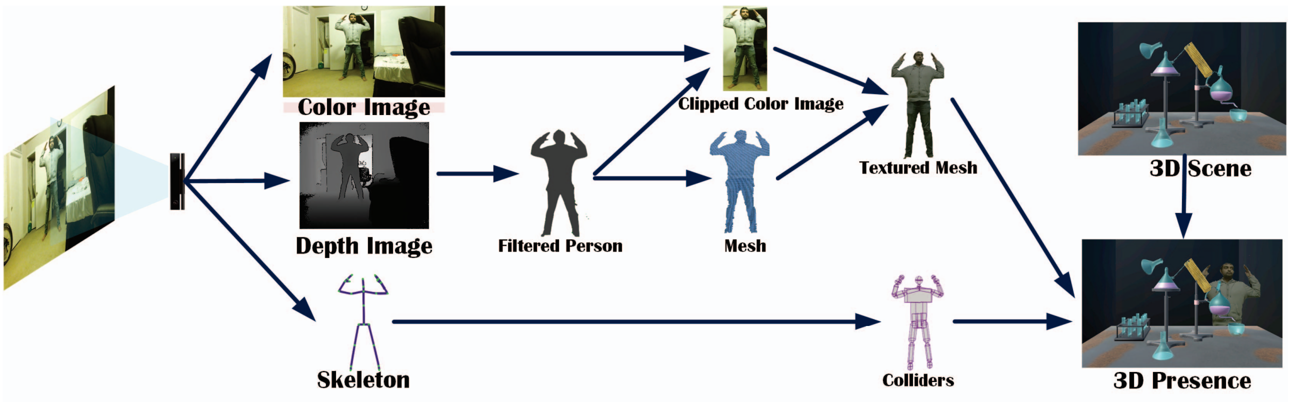


Figure 2: MMCVL Architecture

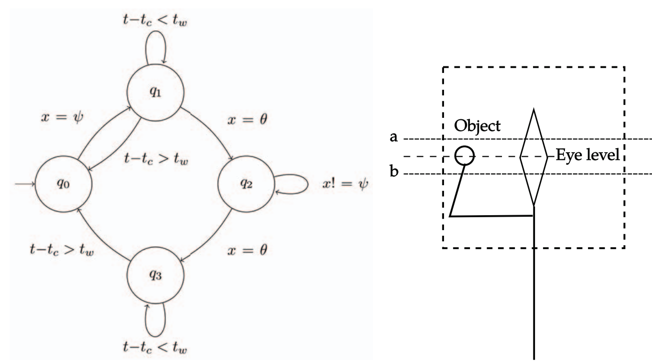
person present in the scene. This 3D mesh along with the skeleton is used in different virtual environment to perform various interactive tasks. The skeleton and mesh information is continuously exchanged among the collaborating sites to carry out real-time experiments in the virtual laboratory.

MMCVL uses Unity Game Engine and Unity Physics to facilitate the multimodal interactions with virtual objects present in the scene. Gesture based interactions are handled using a capsule collider on the human body skeleton. The Physics interactions are transferred over the network through Unity networking. Movement of the object is controlled by the local site but replicated over the remote site though the Unity networking module. Virtual reaction effects are obtained using Unity particle systems. Collaboration aspect is enhanced using audio communication provided through the in-built microphone array of Kinect V2.

Feedback is provided within the system using virtual cameras mounted on the person's head. Virtual zooming and panning effect can be obtained using the head-mounted virtual camera in the minimap representation, shown in Figure 4. This minimap representation provides detailed information to improve the accuracy and efficiency of the virtual training. Along with the minimap and audio communication, virtual feedback in terms of the correct/wrong method of performing the experiment can be given within the system through recorded videos.

B. MMCVL Functionality

Object interactions performed in the system fall into two categories - (1) physical interaction & (2) head tracking. Physical interaction with the object is described as a finite state machine, Figure 3a. The tracked skeleton obtained by the system along with the hand gestures (close/open fist) provided by Kinect are used for picking/dropping objects. First, we define a set of states $S = \{q_0, q_1, q_2, q_3\}$, q_0 and a set of inputs $I = \{\phi, \theta, \psi, t\}$. Input ϕ is for open fist, θ is for closed fist, ψ is for any other hand configuration, and t is the current time. In state q_0, the machine waits for an open



(a) (b)

Figure 3: Object Interactions - (a) Finite State Machine (b) Detection Region

fist to come in contact with an object. Upon contact with the object, the FSM enters state q_1 and wait for the closed fist gesture. We use the variable t_w as the waiting time. State q_2 is triggered when the fist is closed. We attach the object to be the child of the hand, allowing it to translate and rotate as per the hand motion. When an open fist is detected while is state q_2, we transition to state q_3 and allow the object to fall and land at the designated spot.

Head tracking is used to detect when the object is at the eyes level. We use the joint positions provided by the skeleton to measure the elevation of the object. Using the joint position, we define a field of view. This field of view is used to show a camera when the object is closer to the head, in-turn helping in the proper positioning. Figure 3b shows a sketch of the detection region. The object is assumed to be in correct position if it is in between lines a and b.

The joint positions given by the skeleton tracker are not always accurate. In some scenarios, for example - when the arms are too close to the body, the joint positions are noisy enough to induce errors in the object positioning. A mean FIR filter using ten samples is applied to obtain smoothness in the hand movements. For head tracking interactions, we develop a mechanism to define particular points of the object that we want to see. In the chemistry lab experiments, we need to see the meniscus - liquid level in the graduated cylinder. Defining such object provide a easy way to calculate the detection region and provides better tracking.

Recording mechanism is provided in MMCVL to allow for future reference - training and testing. MMCVL has a database at the backend for recording and storing the entire session. Recording of the session can be controlled in terms of the type of data recorded - 3D mesh of the person, human skeleton, audio communication, personal information and experiment data. Based on the data, we can record the live model of the person (mesh and skeleton) performing the experiments. This type of recording will not contain any context information related to the experiment. MMCVL also provides an option to record the entire screen of the virtual setup. This will not only record the 3D person but also record the virtual objects present in the environment. This is done by performing screen captures within Unity. These recordings can be used for future reference so as to understand how the user performed the experiment. Along with the entire session recording, MMCVL also provides a feature to record only part of the session based on the correctness of the performed action. If the user did not correctly perform the action required by the experiment, the recording system will automatically tag it as an erroneous/anomalous movement and record it separately. Such a recording system allows for the teacher to not be present at the time of experiment performance, but still monitor and control the progress of the student.

Along with the video recordings, personal and statistical data can also be recorded and stored for analysis. Personal information can be in terms of the age, gender, science level, familiarity with 3D environments, etc. Such information can be useful to understand how trained or knowledgeable the person is. Apart from this, the statistical information is also stored for the purpose of future reference and improvements. A log of time taken, errors made while performing the experiments, actual and measured liquid levels in each trials are recorded. This log is used to analyze the performance and improvement in learning the real-world experiments, explained in Section V.

IV. MMCVL as Chemistry Lab

MMCVL can serve as different STEM laboratories by incorporating appropriate virtual environments. For the purpose of evaluation, MMCVL has been installed in one of the campuses of Dallas County Community College District (DCCCD) - Eastfield College as a virtual chemistry laboratory. We identified two basic chemistry experiments that train students to measure the volume of liquids using graduated cylinders without parallax error. MMCVL is used to generate the two virtual Chemistry lab experiments.

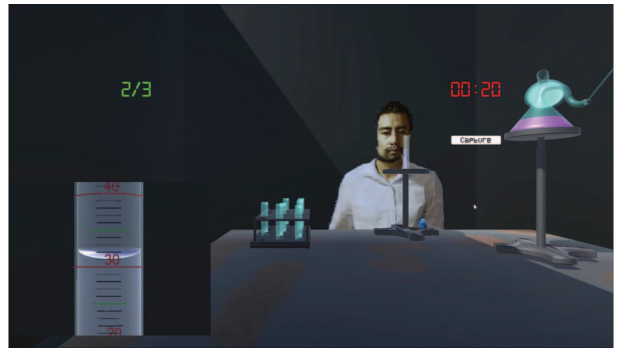


Figure 4: Student Measuring Virtual Graduated Cylinder in the Chemistry MMCVL

Experiment 1: Virtual Training for Measuring without Parallax Error: The goal of this experiment is to train students on the importance of measuring the volume of liquid in a graduated cylinder without parallax error. Student participants "enter" a virtual chemistry lab where a graduated cylinder is shown on a table, Figure 4. Participants stand before the camera and "press" a virtual start button using a hand gesture. The virtual graduated cylinder will now be filled with liquid to a randomized level. Participants visually estimate the level and provide the measured value. MMCVL will then give a feedback whether the measurement was correct. If wrong, it will provide clues for getting it right. Each participant gets 3 attempts in MMCVL and then, they go to a real lab and do the same experiment once with the real graduated cylinder.

Experiment 2: Tele-immersive Training with the Instructor: The goal of this experiment was to test the efficacy of MMCVL in providing tele-immersive STEM laboratory education. For this, MMCVL is configured with 2 "sites" (each site equipped with similar hardware-software setup). Laboratory instructor is at one site and the student participant is at the other site. As shown in Figure 1b, instructor and student will interact in the virtual chemistry laboratory. The instructor will pass a virtual graduated cylinder labeled as A containing a liquid (level decided randomly by the instructor) to the student and ask the student to change the volume to another random level. The instructor will also show how to take the correct measurement, if needed. Then the instructor will give another virtual cylinder labeled as B to the student and the process is repeated. Next, the instructor will ask the student to pour liquids in A and B into a beaker. Animation is used to show the effect of chemical reaction.

V. Experimental Setup & User Study

User studies were carried out on students' Quality of Experience (QoE) with the 2 MMCVL-enabled Chemistry experiments at the Eastfield College of DCCCD. Entire setup requires only one computer/laptop at each site for process-

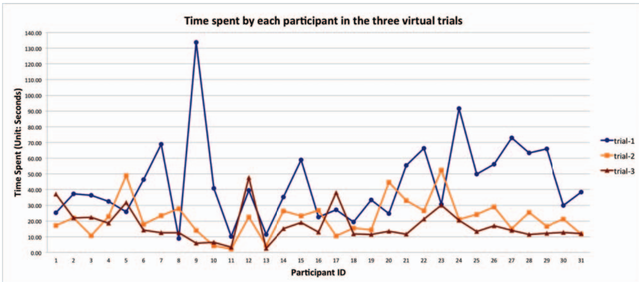


Figure 5: Time taken by each participant in 3 trials for measuring the meniscus level.

ing, one display to see and enjoy the games and a single Microsoft Kinect V2 for motion capture. The computer should be able to run graphics intensive application and thus should have a good graphics card, sufficient RAM and relatively new processor. Two computers were used in the experimental study for Chemistry Lab experiments. Experiment-1 only uses one laptop where as Experiment-2 uses one laptop and one desktop since it is a collaborative setup having two sites. Both the computers had a GTX 950 graphics card, Intel i7 2.4 GHz processor and 16 GB RAM. Samsung 3D TVs were used as primary displays. Two Microsoft Kinect V2 were used, each connected to the computer using a USB 3.0. The entire framework for motion capture and 3D mesh generation and transmission is written in C++ whereas the game development is done in Unity3D game engine using OpenGL rendering and PhysX for physics. A total of 31 participants volunteered for the user study - 11 male and 20 female. 2 Chemistry/Biochemistry faulty, students and staff in the age range 18 to 65 years volunteered for the study. The participants belonged to different majors and had different science skill level. 4 of the participants had some prior experience in virtual training.

In experiment 1, the users had to take 3 trials for measuring the meniscus level in the graduated cylinder. We recorded the original level, observed level as well as the time spent by each user in every trial. From the recorded values, we find that the users spent on an average $43.84s$ (SD - $26.06s$) for trail-1, $21.83s$ (SD - $11.73s$) for trail-2 and $17.26s$ (SD - $10.29s$) for trail-3. Figure 5 shows the time taken by each participant in all 3 trials. We can see that the time taken for the user to measure the liquid level significantly reduced in corresponding trials.

Participants measured the liquid level in all 3 virtual experiment trials. In all trials, the user measurements were allowed an error rate of $\pm 0.2ml$. Apart from virtual experiment trials, the users had to measure the liquid level in a real graudated cylinder which was set up by a Chemistry professor at the demo location. We compared the correct measurements with the observed measurements of the users in each trial. Among all participants, the average accuracy of the observed measurements was 48% for trial-1, 73% for trial-2 and 78% for trial-3. From these values we can see that not only did the users take less time in measuring the levels, but also became more accurate in the consecutive trials. On an average for all 31 participants, the max error rate for measuring the liquid level in the virtual trials was 3.84%. This average error rate went down to 3.44% for the liquid measurement in the real experiment. The error rate decrease in measuring the liquid reduced by about 10.4% which is quite significant. In a related analysis, we compute the change in the error rate for measuring the liquid level between two virtual trials as well as between the max error rate in virtual trials to the real experiment. The average error rate decreased consecutively from virtual trial-1 to trial-2 by 0.37%, from trial-2 to trial-3 by 0.11%. Also, the reduction from the max average error rate from the 3 virtual trials to the real experiment was 0.4%. Thus, not only does the individual improve performance in the consecutive virtual trials but it also improves from virtual to the real-world experiment. From the above analysis, we can say that, after using the system individuals felt more confident and were trained enough to get an improvement in their performance.

Table I: User study questionnaire & average scores, using a 7 point Likert-type scale from -3 to 3.

Question	Avg Score
Experiment-1	-
I could interact with the virtual objects easily.	1.93
My movements were correctly replicated.	2.00
This system has all the functions and capabilities I expect it to have, to finish the task.	1.93
I felt a part of the virtual world shown on TV.	1.81
Overall, I am satisfied with the use of this system.	2.15
The system allows me to be physically evaluated as effectively as I would be in a standard in-person evaluation.	1.36
In comparison with a standard in-person evaluation, it is as easy to interact and collaborate with remote person using this system.	1.69
Overall, I believe this system has potential to replace standard in-person lab setting.	1.33
Experiment-2	-
I Could see the other person's actions clearly.	2.31
There was no noticeable delay while interacting with other person.	1.93
I could effectively communicate with the other person.	2.31

Users were also asked to fill out an online survey for both the experiments. The questions asked are as shown in Table I. 7 point Likert-type scale from -3 to 3 was used for the responses. The table also shows the average score given by all the users. The questions for experiment-1 mainly focused on evaluating the quality of experience and comparison to the in-person evaluation. Whereas the questions for experiment-2 focused on the quality of collaboration. Based on results shown in table, all the aspects of MMCVL were really appreciated.

From individual feedback, almost everyone liked the experiments and believed that it had tremendous potential to replace traditional laboratory setting. One of the users provided the following comment - "As an initial attempt this system has lot of potential to make an epic change to today's laboratory settings. I would love to see further development in the field and experience the all finished VR experience". Another person commented on the use of Virtual lab - "I am curious about chemistry but equally intimidated by the topic. I felt very safe trying out the experiment virtually". There were also some negative comments regarding the interactions involved, mainly the fist detection. Kinect needs the palm to be facing towards the camera to accurately detect the open/close fist, which was not really intuitive for some users. Overall the system was well appreciated with potential not only in Chemistry but in other lab settings as well.

VI. Conclusion & Future Work

The proposed MMCVL system provides a 3D Tele-Immersive environment for performing different experiments. Different laboratory settings can be created to suit the specific needs of the subject. The collaborative nature of the system along with the audio communication and video feedback improves the virtual experience level for users. The recording module helps to further enhance the learning and testing of user performance. Apart from being useful for learning, the MMCVL setup turns out to be fun, engaging and at the same time motivating enough to perform repetitively. The setup is affordable, easy to use and suitable for teaching college students due to the fact that it requires only one computer, a TV and a Kinect camera. MMCVL has high potential in revolutionizing the way current laboratory teaching works.

In terms of improving the system, we plan to improve the close and open fist detection algorithm provided by Kinect. We also plan to improve the interactions with the virtual objects so as to increase the realistic feeling. Given our preliminary positive findings for the usability and satisfaction with our system, we are pursuing research along with other faculties to evaluate the feasibility and effectiveness in different laboratory settings. We also plan to incorporate Olfactory devices to release smell when a chemical interaction occurs in the virtual environment. This will further enhance the immersive experience provided by MMCVL.

Acknowledgment

This material is based upon work supported by the National Science Foundation under Grant No. 1012975. Any opinions, findings, conclusions or recommendations expressed in this material are those of author(s) and do not necessarily reflect the views of the National Science Foundation.

References

[1] X. Chen, "Stem attrition: College students' paths into and out of stem fields. statistical analysis report. nces 2014-001." *National Center for Education Statistics*, 2013.

[2] J. Wellik, O. Lee, and C. A. Buxton, "Diversity and equity in science education," 2011.

[3] T. De Jong, M. C. Linn, and Z. C. Zacharia, "Physical and virtual laboratories in science and engineering education," *Science*, vol. 340, no. 6130, pp. 305–308, 2013.

[4] L. C. Hodges, *Teaching Undergraduate Science: A Guide to Overcoming Obstacles to Student Learning*. Stylus Publishing, LLC, 2015.

[5] S. M. Montenery, M. Walker, E. Sorensen, R. Thompson, D. Kirklin, R. White, and C. Ross, "Millennial generation student nurses perceptions of the impact of multiple technologies on learning," *Nursing education perspectives*, vol. 34, no. 6, pp. 405–409, 2013.

[6] S. Goldrick-Rab, "Promoting academic momentum at community colleges: Challenges and opportunities. ccrc working paper no. 5." *Community College Research Center, Columbia University*, 2007.

[7] *Promoting Academic Momentum at Community Colleges: Challenges and Opportunities*, available at https://ccrc.tc.columbia.edu/media/k2/attachments/academic-momentum-community-colleges.pdf.

[8] L. Cruz, D. Lucio, and L. Velho, "Kinect and rgbd images: Challenges and applications," in *Graphics, Patterns and Images Tutorials (SIBGRAPI-T), 2012 25th SIBGRAPI Conference on*, Aug 2012, pp. 36–49.

[9] Z. Tatli and A. Ayas, "Effect of a virtual chemistry laboratory on students' achievement." *Educational technology & society*, vol. 16, no. 1, pp. 159–170, 2013.

[10] K. Pyatt and R. Sims, "Virtual and physical experimentation in inquiry-based science labs: Attitudes, performance and access," *Journal of Science Education and Technology*, vol. 21, no. 1, pp. 133–147, 2012.

[11] C. Moro, Z. Stromberga, A. Raikos, and A. Stirling, "Combining virtual (oculus rift & gear vr) and augmented reality with interactive applications to enhance tertiary medical and biomedical curricula," in *SIGGRAPH ASIA 2016 Symposium on Education: Talks*. ACM, 2016, p. 16.

[12] P. E. Pelargos, D. T. Nagasawa, C. Lagman, S. Tenn, J. V. Demos, S. J. Lee, T. T. Bui, N. E. Barnette, N. S. Bhatt, N. Ung *et al.*, "Utilizing virtual and augmented reality for educational and clinical enhancements in neurosurgery," *Journal of Clinical Neuroscience*, vol. 35, pp. 1–4, 2017.

[13] Y. Jiang, L. Paquette, R. S. Baker, and J. Clarke-Midura, "Comparing novice and experienced students within virtual performance assessments." *International Educational Data Mining Society*, 2015.

[14] *Pitsco - STEM Expeditions*, available at http://www.pitsco.com/Curriculum/Integrated_STEM/STEM_Expeditions.

[15] *Lifeliqe*, available at https://www.lifeliqe.com/.

[16] *zSpace*, available at http://edu.zspace.com/.

[17] *Immersive VR Education*, available at http://immersivevreducation.com/.

[18] K. Desai, K. Bahirat, S. Ramalingam, B. Prabhakaran, T. Annaswamy, and U. E. Makris, “Augmented reality-based exergames for rehabilitation,” in *Proceedings of the 7th International Conference on Multimedia Systems*. ACM, 2016, p. 22.

[19] K. Desai, K. Bahirat, S. Raghuraman, and B. Prabhakaran, “Network adaptive textured mesh generation for collaborative 3d tele-immersion,” in *Multimedia (ISM), 2015 IEEE International Symposium on*. IEEE, 2015, pp. 107–112.

[20] *Video for Tele-Rehab system*, available at http://www.utdallas.edu/~praba/tele-rehab.mp4.

[21] *Tele-Rehab in Austin American Statesman*, available at http://www.mystatesman.com/news/news/state-regional-govt-politics/texas-veterans-first-to-test-new-cyber-rehab-techn/nnwtw/.

[22] *Soccer Penalty Game*, available at http://www.utdallas.edu/~praba/penalty.mp4.

[23] J. Shotton, A. Fitzgibbon, M. Cook, T. Sharp, M. Finocchio, R. Moore, A. Kipman, and A. Blake, “Real-time human pose recognition in parts from a single depth image,” in *CVPR*. IEEE, June 2011. [Online]. Available: http://research.microsoft.com/apps/pubs/default.aspx?id=145347

[24] S. Raghuraman, K. Venkatraman, Z. Wang, B. Prabhakaran, and X. Guo, “A 3d tele-immersion streaming approach using skeleton-based prediction,” in *Proceedings of the 21st ACM International Conference on Multimedia*, ser. MM ’13. New York, NY, USA: ACM, 2013, pp. 721–724. [Online]. Available: http://doi.acm.org/10.1145/2502081.2502188