Using WebGL to Implement a Glass Lens in Online Labs

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***Abstract*— Online Labs are revolutionizing education by offering access to content anytime and from any place. The OLabs project has had a deep impact on learning capabilities of students by providing an integrated environment that includes videos, animations, simulations and textual content. It has also helped to substitute teachers wherever there have been gaps. OLabs offers an excellent platform for the improvement of Science, Technology, Engineering and Maths (STEM) education which has been the focus of several countries in recent times.**

The current content in OLabs is 2 dimensional. 2D content comes with its own limitations of low accuracy and low realism and hence moving to browser based 3D representations is important to offer an enriching experience to the learner. WebGL offers the powerful capability of rendering 2D as well as 3D content in any browser without the need to install additional applications or components. With the advent of WebGL, writing 3D applications have become simpler since most details are abstracted from the programmer. New features are added almost every week in WebGL by the community making it rich and powerful. In this paper we present our work on implementing, in 3D, a convex lens experiment in OLabs Physics using WebGL and dynamic cube mapping. We propose to extend this work to more experiments in Physics and Chemistry, demonstrate it to students and measure their learning.

Keywords— Online Labs, WebGL, Dynamic Cube Mapping

I. INTRODUCTION

In today's world teaching and learning has evolved from a simple chalk and talk method to more sophisticated blended learning experience where multimodal content is used. Animations, games, video and audio have all becomes part of mainstream education, thanks to the power of technology.

One of the key elements of the teaching-learning process is the laboratory component. Labs offer a hand-on experience, critical thinking skills and develop a problem-solving attitude in students. Educational institutions often find themselves investing a great deal of money for advanced lab equipments. In a country like India where there 85% of schools are rural schools, building labs become almost impossible considering the high cost associated with construction and maintenance. In such a scenario, the concept of Online and Virtual Labs offer immense benefits. Online Labs facilitate lab experiments to be conducted online using animations and simulations and advancements in technology are bringing the experience as close to reality as possible [10].

According to the theory of Experiential Learning, learning is an iterative process which is enhanced and enriched by experience. A four stage model of Learning has been proposed by David A. Kolb [1]. As per the model, the first stage is the concrete experience stage where the learner is involved in a new experience. The learner then reflects on his own experience in the reflective observation stage. A theory is then created by abstracting out concepts in the Abstract Conceptualization stage and finally the learner uses these theories to solve problems in the Active experimentation stage. Hands-on experience through Online Labs gives direct experience to students thereby increasing their capability to apply what they have learnt. With its integrated content, OLabs covers all aspects of the experiential learning model. More research and development may be required in the creation of content which accurately depicts theory and that which can give the right perception to students using it. In this context, the use of computer graphics to render simulations accurately and effectively in 3D can help students to directly translate theory into practice.

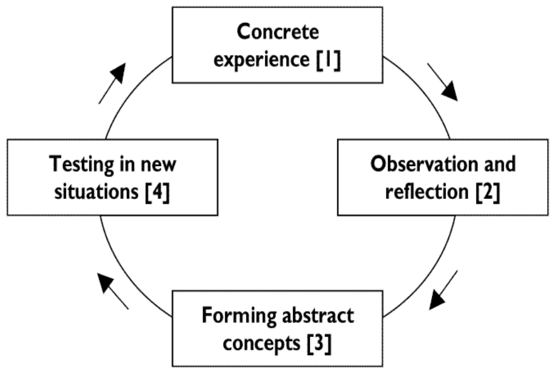

Fig 1: Experiential Learning Model

In our paper we present in detail the design and development of a few virtual lab experiments in 3D using WebGL. Our paper is organized as follows. In Section II we present background information on Simulations in learning, WEBGL and the OLabs project. We have presented a few

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related works in Section III. Section IV covers basics of lens and what may be required for a 3D rendering of a lens. In Section V we discuss the methodology used to implement a 3D lens in OLabs Physics lab. We have concluded in Section VI.

II. BACKGROUND

With rapid advancements in technology, there is a need for more and more people who are not just users of technology but also creators of the same. A more intelligent workforce is needed to meet the growing needs of nations. No wonder, several countries are working towards enhancing their Science Technology Engineering and Maths (STEM) curriculum inoder to create a better workforce for the future [13, 15]. The goals of STEM education are shown in Figure 2. For enhancing STEM education, countries are looking at strengthening the STEM course content right from primary school. Schools are trying to integrate as many aspects as possible to deliver high quality STEM education some of which include use of Project Based Learning, Multimodal content like videos, simulations and presentations and Hands-on Approach to learning. STEM educators have recognized the importance of using interactive simulations in classroom and have found that simulations enhance learning mainly because students are able to visualize complex scientific concepts [14].

Ensure a STEM-capable citizenry	Build a STEM-proficient workforce
❖ This goal seeks to cultivate a citizenry that has "the knowledge, conceptual understandings, and critical-thinking skills that come from studying STEM subjects." This is important even for those who never directly enter a STEM-related career.	❖ This goal seeks to adequately prepare a sufficient number of workers for job openings in STEM-related careers which are expected to increase in coming years. Additionally, STEM-related skills are increasingly relevant in fields not directly related to STEM subjects.
Cultivate future STEM experts	**Close the achievement and participation gap**
❖ This goal aims to educate the best STEM experts in the world because they contribute "to economic growth, to technological progress, to our understanding of ourselves and the universe, and to the reduction of hunger, disease, and poverty."	❖ This goal aims to increase women and minority participation and interest in STEM fields in order to tap into the country's full potential.

Fig 2 . Goals of STEM Education
Source: PCAST and K-12 Education Overview, Hanover Research

A. Simulations for Learning

Often scientific concepts are perceived to be complex by many learners owing to their multi dimensionality. Visual representations, especially interactive type, of scientific concepts have always been an interesting topic of research for many educational researchers because they offer a number of benefits to learners, some of which include:

- Helps the creation of an accurate mental model of concepts
- Helps learners to change multiple aspects and view the resulting effects
- Integrates multiple scientific domains like maths, physics and chemistry
- Simplifies complex abstractions by use of different colors, viewing angles and modes
- Enables repetitive learning, thereby facilitates better retention of concepts

Simulations are perceived as an aesthetic way of rendering scientific concepts. For example, electromagnetism simulations have been developed and their impact has been analyzed in [17]. Interactive simulations also enable a constructivist approach to learning by encouraging "learning by doing" [2]. Hence simulations are an excellent means by which teachers can explain advanced scientific concepts and learners can retain and apply these concepts more efficiently. A meta-analysis of simulations and games conducted by Jennifer J. Vogel highlights that subjects using interactive games and simulations often outperformed those who were taught by traditional means. Also, the more realistic these simulations were, the better they were able to engage students. One of the key findings of this meta-analysis was that, such simulations promoted very high degree of self-learning [11].

The Physics Technology Education project has been extremely successful in creating Physics based animations and simulations for students. PHET adopts a game-based learning approach to Physics with interactive simulations that allow click-drag manipulations. A feedback was obtained from students who used the simulations and nearly 62% of them found them extremely useful [18].

B. OLABS

OLabs (Online Labs) is a project jointly developed by Amrita University and CDAC. The project was sponsored by Department of Information Technology, India. OLabs. OLabs offers an excellent online learning platform for STEM education. OLabs has the following features:

- Interactive simulations, animations and videos for various science and maths concepts
- Physics and Chemistry Labs for Class 9 and 10
- Content has been created to match the Central Board of Secondary Education (CBSE) curriculum
- The experiments can be accessed at anytime from anyplace with internet connection

OLabs was recommended by CBSE as a teaching and learning aid to the 15000 schools that follow the CBSE curriculum. The main advantage of OLabs is that it eliminates the time and cost associated with the setup of advanced lab equipments [8]. Also, experiments that are not practically possible through equipments can easily be offered as simulations on OLabs. OLabs offers a multi-pronged learning environment with not just learning content but also an integrated assessment module to evaluate the retention skills, understanding capabilities, procedural and manipulative skills and interpreting skills of students.

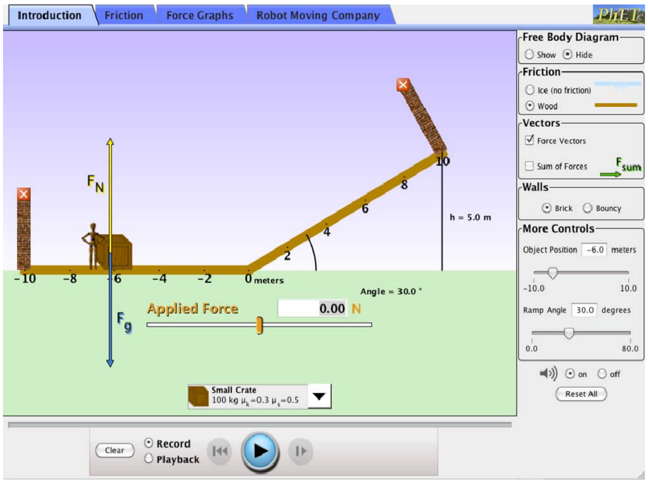

Fig 3. Sample PHET simulation
Source: [18]

In our previous study on OLabs, we had compared traditional lab learning with OLabs based learning and evaluated if OLabs content adapted to tablets comparable to OLabs desktop content [7] . Our study of OLabs showed that when compared to traditional labs, students using OLabs had a significant performance improvement in conceptual skills than in traditional labs and the effectiveness of tablet based OLabs was as effective as the desktop based content. The idea that experiments could be repeated any number of times without the wastage of actual chemicals in chemistry lab seem to make OLabs a very appropriate platform to conduct experiments. The Virtual Labs (VLABS) initiative of MHRD project has been able to demonstrate that its ease of use, trialability and accessibility has great impact on its adoption among students of Engineering and Technology [9]. These studies give us insights into the power use of technology enhancing the teaching learning process. Hence it is important that the content offered is of very high quality. Quality is not only in terms of the complexity of content offered but also how accurately we are able to present ideas. Such accuracy, especially with respect to simulations, is achievable only through use of high quality graphics based rendering of content. Currently, the content in most OLabs experiments in rendered in 2D. Though these simulations have had a good impact on students, they have certain limitations:

- The *realism* factor is low for 2D simulations
- The accuracy of rendering when viewing angle changes is low in 2 D simulations
- The experience of real world interaction is very low with 2D
- Accuracy of rendering is low in the case of 2D renderings especially when the image locations changes or the viewing angle changes

Therefore, gradually migrating to 3D simulations in OLabs seemed to be the next logical step. In the ensuing sections we shall discuss how we designed the convex lens experiment in Physics OLabs.

C. *WEBGL*

Most multimodal educational content on the web is 2 dimensional in nature. However, learners of the modern age who are technology savvy prefer content to be rendered in 3D. Hence significant efforts are going into rendering web based content in 3D. Most of such content exists in ecommerce sites. Offering learning content in 3D is important for the following reasons:

- Modern learners are very comfortable with technology and look for closer to reality experience while learning
- The accuracy of 2D content is limited, which may be an impediment to correct learning
- Given the attention span of modern learners, more interesting and exciting content may be required to keep them engaged.
- Current technology does not allow for the geometric representation of complex concepts which can only be represented in 3D

Very little work has gone into offering learning content in 3D owing to the several challenges involved ranging from lack of expertise to the lack of suitable simple technology. Thanks to WebGL, most of these challenges can be overcome.

WebGL is the latest technology that comes packed with HTML5 that solves the problems of high end graphics on the web [16]. With the possibility of writing OpenGL code in javascript, it has become very easy to build the state of the art graphics applications that deliver an output that does not compensate on performance. WebGL (Web Graphics Library) is a JavaScript API for rendering interactive 3D graphics within any compatible web browser without the use of plug-ins. WebGL programs consist of control code written in JavaScript and shader code that is executed on a computer's Graphics Processing Unit (GPU). WebGL is designed and maintained by the non-profit Khronos Group. WebGL offers the following benefits over the earlier VRML:

- WebGL need not be added as a Plugin but built into modern browsers.
- WebGL is greatly benefitted by hardware accelerated graphics.
- WebGL is not separate from JavaScript i.e its set of bindings in JavaScript, hence it makes life simpler for programmers who are comfortable with JavaScript.

III. RELATED WORK

In [4], John Congote et al have implemented a volume rendering system for the web. They demonstrate this using two case studies namely medical and weather radar imaging. They have used WebGL for this purpose. Reference [5] highlights the use of WebGL for the development of a web-based interactive medical learning system. They mention that rendering high quality 3D meshes and videos using WebGL can be extremely helpful during planned surgeries and training of doctors and assistants. Bartosz Sawicki, Bartosz Chaber in [12] have presented their work on 3D mesh viewer using HTML 5 technology. They have tested the rendering on different devices as well as browsers. They found that such rendering is reasonably good in tablets and smartphones but better on netbooks and laptops. Zhu et al have developed an interactive web–based system for learning human anatomy. By providing Microsoft Kinect integration, users of the system can navigate with the help of hand gestures. They have experimentally demonstrated the usefulness of the system in clinical applications [3]. Isik-Ercan, Zeynep, Beomjin Kim, and Jeffrey Nowak in [6] have conducted a pilot study of how 3D stereoscopic vision can help second graders understand the shape of celestial objects, how day and night alternate and how moon appears in different shapes. The authors found that with the support of rendering technologies, very young kids are easily able to understand advanced concepts.

IV. THE MYSTERIES OF A LENS

Implementing a lens is not a trivial task, especially the rendering of refraction. Refraction is the change in direction of a wave due to a change in its speed. As a light ray travels from one medium(air) to another (glass of the lens, our concern), the speed decreases, the frequency remains constant and the light ray bends in some other direction if the angle of incidence is something other than 90 or 0 degrees. Refraction is described by Snell's law, which states that for a given pair of media and a wave with a single frequency, the ratio of the sines of the angle of incidence θ1 and angle of refraction θ2 is equivalent to the ratio of phase velocities (v1 / v2) in the two media, or equivalently, to the opposite ratio of the indices of refraction (n2 / n1):

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

Some principles of a lens that are important for graphics based implementation is that the lens is a part of a sphere and the radius of curvature is the radius of the sphere of which the lens is a part of. Also, the radius of curvature, the focal length and the refractive index are related by the formula

$$\frac{1}{f} = (n-1) * \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Where f is the focal length, n is the refractive index, R_1 and R_2 are the radii of curvature of the surfaces of the lens. The big challenge while implementing a lens, is the rendering of the image when the viewing angle or the object location changes. Hence it requires sophisticated 3D technology to accurately render this.

V. METHODOLOGY

In this section we discuss the methodology adopted to implement the Optics Lab concept in Physics. We explain the modeling of the fully functional convex lens using the cube mapping technique. We have used a cube camera for the images and used the three.js 3D java library to render the lens effect. A sample lab setup is shown in Figure 4 where the lens is kept between the object and image needles. The aim of the experiment shown in Figure 4 is to find the different values of v (the distance of the image pin from the lens) for different values of u (the distance of the object pin from the lens) such that it satisfies the thin lens equation

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Inorder to render this lab, the following need to be implemented:

- Mapping the image of the surroundings (including the object pin) on the lens
- A realistic rendering refraction
- Object pin image location to respond to changes in viewing angle
- Changing the location of object pin image

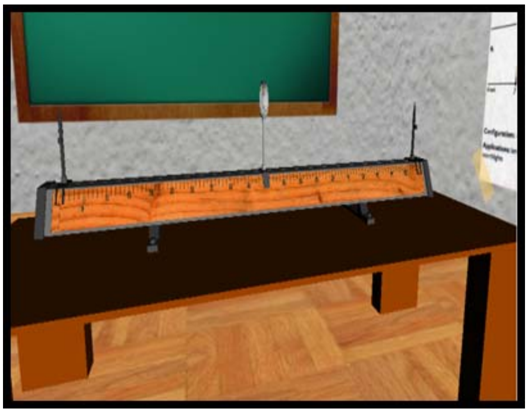

Fig 4: A sample Convex Lens Lab Setup in OLabs

The above mentioned features can be achieved using the following technologies:

- The mapping of the environment on the lens is done by using the cubecamera. Inorder to render images realistically, we put 6 cameras facing the 6 sides of the cube perpendicularly to them. The images rendered by the 6 cameras will be mapped onto the 6 sides of the cube. This works for all 3D objects. Figure 5 shows the view of the pin from the other side of the lens. When the lens is moved along the optic bench, the image is re-rendered accordingly.
- A realistic rendering of refraction is achieved using cube refraction texture provided by three.js. The texture initialization takes the refraction ratio (the ratio of the indices of refraction of the 2 media) of the lens as argument. This gives a bulgy effect of the convex lens.

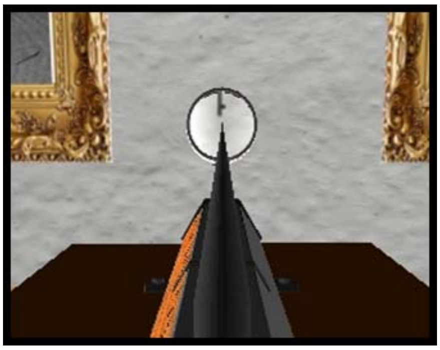

Fig 5: View of Pin from other side of Lens

- As we move the camera location to different points on the horizontal line, the image will move in real world. This visualization depends on the mesh that is used to build the lens coupled with the help of the refraction texture. The mesh that we used was modeled in Blender 3D, one side of which is part of a sphere of radius = Radius of curvature of the lens. So more the radius of curvature, the more is the noted movement of the image for a particular viewing angle as depicted in Figure 6.

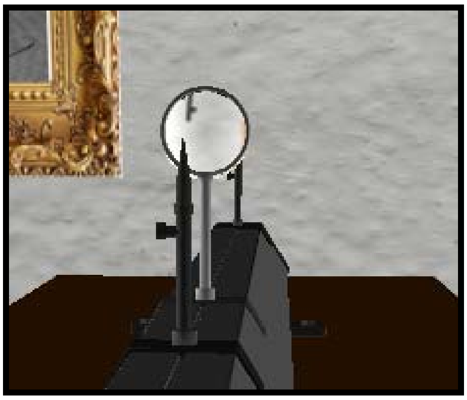

Fig 6: Change in Viewing Angle

- As the object pin is slid along the optic bench, the image in the lens is observed to become smaller and moving towards the centre of the vertical line of the lens. This was done by deriving the value of ‘cubeCameraMax’ which is later used to reposition the cube camera to adjust and change the image position. cubeCameraMax is the position of the cube camera when the horizontal movement of the camera has reached its maximum value.

$$cubeCameraMax = ObjectPosition - 2 * \frac{f}{10}$$

VI. CONCLUSION

Learning STEM subjects is a complex process involving multiple dimensions. Working towards innovatively imparting STEM education is very important not just for the benefit of the students but also for the growth of the nations since it opens up new job opportunities and helps nations develop a competitive advantage over other nations. One of the important dimensions of STEM education is multimodal content that is of high quality in terms of its availability, accessibility and accuracy. That is where OLabs simulations, especially rendered in 3D help to bridge the gaps in understanding of STEM concepts by students.

In this paper, we have presented the methodology we have adopted to implement a 3D glass lens using the dynamic cube mapping technique and rendering the same with WEBGL. This way we have made the convex lens experiment more realistic and accurate. As future work we propose to

- Extend this to a few more experiments in chemistry and physics
- Demonstrate these experiments to students and collect their feedback
- Compare how effectively students are able to retain, understand and apply various concepts by learning from 2D and 3D content
- Record the satisfaction of students in using 3D content, interacting with simulations in 3D and accuracy of the representations

REFERENCES

[1] D. A. Kolb, “Experiential Learning”, Englewood Cliffs, NJ: Prentice-Hall, 1984.

[2] Ha, Oai, and Ning Fang. "Development of interactive 3D tangible models as teaching aids to improve students' spatial ability in STEM education." Frontiers in Education Conference, 2013 IEEE. IEEE, 2013.

[3] Zhu, Haichao, et al. "An Interactive Web-Based Navigation System for Learning Human Anatomy." Advanced Technologies, Embedded and Multimedia for Human-centric Computing. Springer Netherlands, 2014. 73-81.

[4] Congote, John, et al. "Interactive visualization of volumetric data with webgl in real-time." Proceedings of the 16th International Conference on 3D Web Technology. ACM, 2011.

[5] Birr, Steven, Jeanette Mönch, Dirk Sommerfeld, Uta Preim, and Bernhard Preim. "The LiverAnatomyExplorer: A WebGL-based Surgical Teaching Tool." (2013): 1-1.

[6] Isik-Ercan, Zeynep, Beomjin Kim, and Jeffrey Nowak. "Can 3D Visualization Assist in Young Children’s Understanding of Sun-Earth-Moon System?." International Journal of Knowledge Society Research (IJKSR) 3.4 (2012): 12-21.

[7] Nedungadi, Prema, Raghu Raman, and Mark McGregor. "Enhanced STEM learning with Online Labs: Empirical study comparing physical labs, tablets and desktops." In Frontiers in Education Conference, 2013 IEEE, pp. 1585-1590. IEEE, 2013.

[8] Raman, Raghu, Prema Nedungadi, and Maneesha Ramesh. "Modeling Diffusion of Tabletop for Collaborative Learning Using Interactive Science Lab Simulations." In Distributed Computing and Internet Technology, pp. 333-340. Springer International Publishing, 2014.

[9] Raman, R.; Achuthan, K.; Nedungadi, P.; Diwakar, S.; Bose, R., The VLAB OER Experience: Modeling Potential-Adopter Student Acceptance, Education, IEEE Transactions on , vol.PP, no.99, pp.1,1

[10] Müller, Dieter, and José M. Ferreira. "Online labs and the MARVEL experience." International Journal of Online Engineering 1, no. 1 (2005): 5.

[11] Vogel, Jennifer J., et al. "Computer gaming and interactive simulations for learning: A meta-analysis." Journal of Educational Computing Research 34.3 (2006): 229-243.

[12] Sawicki, Bartosz, and Bartosz Chaber. "3D mesh viewer using HTML5 technology." *Przeglad Elektrotechniczny (Electrical Review), ISSN* (2012): 0033-2097.

[13] Sanders, Mark. "Stem, stem education, stemmania." *The Technology Teacher* 68.4 (2009): 20-26.

[14] Fairweather, James. "Linking evidence and promising practices in science, technology, engineering, and mathematics (STEM) undergraduate education." *Board of Science Education, National Research Council, The National Academies, Washington, DC* (2008).

[15] Brophy, Sean, et al. "Advancing engineering education in P-12 classrooms." *Journal of Engineering Education* 97.3 (2008): 369-387.

[16] Anttonen, Matti, and Arto Salminen. "Building 3d webgl applications." Tampereen teknillinen yliopisto. Ohjelmistotekniikan laitos. Raportti-Tampere University of Technology. Department of Software Systems. Report; 16 (2011).

[17] Squire, Kurt, et al. "Electromagnetism supercharged!: Learning physics with digital simulation games." *Proceedings of the 6th international conference on Learning sciences*. International Society of the Learning Sciences, 2004.

[18] Perkins, Katherine, et al. "PhET: Interactive simulations for teaching and learning physics." *The Physics Teacher* 44.1 (2005): 18-23.