

Developing VR-Based Solar Cell Lab Module in Green Manufacturing Education

Dr. Richard Chiou, Drexel University

Dr. Richard Chiou is Associate Professor within the Engineering Technology Department at Drexel University, Philadelphia, USA. He received his Ph.D. degree in the G.W. Woodruff School of Mechanical Engineering at Georgia Institute of Technology. His educational background is in manufacturing with an emphasis on mechatronics. In addition to his many years of industrial experience, he has taught many different engineering and technology courses at undergraduate and graduate levels. His tremendous research experience in manufacturing includes environmentally conscious manufacturing, Internet based robotics, and Web based quality. In the past years, he has been involved in sustainable manufacturing for maximizing energy and material recovery while minimizing environmental impact.

Mr. Hieu V Nguyen, Drexel University

Dr. Irina Nicoleta Ciobanescu Husanu, Drexel University

Irina Ciobanescu Husanu, Ph. D. is Assistant Clinical Professor with Drexel University, Engineering Technology program. Her area of expertise is in thermo-fluid sciences with applications in micro-combustion, fuel cells, green fuels and plasma assisted combustion. She has prior industrial experience in aerospace engineering that encompasses both theoretical analysis and experimental investigations such as designing and testing of propulsion systems including design and development of pilot testing facility, mechanical instrumentation, and industrial applications of aircraft engines. Also, in the past 10 years she gained experience in teaching ME and ET courses in both quality control and quality assurance areas as well as in thermal-fluid, energy conversion and mechanical areas from various levels of instruction and addressed to a broad spectrum of students, from freshmen to seniors, from high school graduates to adult learners. She also has extended experience in curriculum development. Dr. Husanu developed laboratory activities for Measurement and Instrumentation course as well as for quality control undergraduate and graduate courses in ET Masters program. Also, she introduced the first experiential activity for Applied Mechanics courses. She is coordinator and advisor for capstone projects for Engineering Technology.

Prof. Tzu-Liang Bill Tseng, University of Texas at El Paso

Dr. Bill Tseng is a Professor and Chair of Department of Industrial, Manufacturing and Systems Engineering at the UTEP. He is also a Director of Research Institute for Manufacturing & Engineering Systems, the host institute of Texas Manufacturing Assistance Center at UTEP. He received his two MSIE degrees (MFG & DS/OR) from the University of Wisconsin at Madison and Ph.D. in Industrial Engineering from the University of Iowa. Dr. Tseng is also a Certified Manufacturing Engineer from Society of Manufacturing Engineers. Dr. Tseng's research area cover emergency management, systems engineering, computational intelligence/data analytics and cyber engineering technology. Over the years, he has served more than 10 million dollars as principle investigators sponsored by NSF, NIST, USDT, DoEd, KSEF and industry like LMCO, GM and Tyco Inc. Dr. Tseng delivered research results to many refereed journals such as IEEE Transactions, IIE Transactions, International Journal of Production Research, Journal of Manufacturing Systems, Expert Systems with Applications and other conferences (over 260 refereed publications). He is currently serving as an editor of Journal of Computer Standards & Interfaces (CSI) and editor boards of International Journal of Data Mining, Modeling and Management (JDMMM) and American Journal of Industrial and Business Management (AJIBM). He is currently a Senior Member of Institute of Industrial Engineers, Society of Manufacturing Engineers and the Division Chair of Manufacturing Division of American Society of Engineering Education (ASEE). He is also actively involved in several consortia activities.

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ABSTRACT

This paper describes the development of a new virtual reality (VR)-based laboratory module in green manufacturing education. The VR laboratory module is intended to provide in-depth learning for students about solar energy efficiency issues to reduce the environmental impact in the industry. The VR solar panel laboratory module is built with the primary purpose of allowing students to be able to work on the solar experiment remotely. Students will be able to gain knowledge and hands-on experience without having to own the physical equipment, and concepts in solar energy engineering can be conveyed effectively. The VR solar panel is built using Unity 3D with the help of the SteamVR development kit. The 3D model of the solar panel is created and rendered with the help of Autodesk 3ds Max. The solar panel is designed to be interactable. Users will be able to virtually grab and turn the solar panel and interact with all the buttons using VR controllers and a VR headset. Three main lab modules are incorporated into the solar panel lab: the angle of the light source with respect to the solar panel's angle, the temperature, and the maximum power point (MPP). The back-end programming of the solar panel is conducted using C#. The back end includes all of the panel's characteristics and all the underlying formulas that generate experimental data. The virtual solar panel laboratory is designed to incorporate seamlessly with the lecture material and can be used to completely replace the physical solar panel lab. Students learn the fundamentals of photovoltaic (PV) effect and virtual reality gives a platform for students to implement the concepts in practice. We will conclude the paper with practical implications in instructional practice.

I. INTRODUCTION

This paper was written in the midst of Global quarantine from the novel Coronavirus COVID-19. The quarantine limited all of the normal face-to-face social events, meetings, lectures, etc. A lot of industries and fields were affected badly by the social distancing policy. Academics was one of the fields that got affected a lot, but not so much in a bad way. Lectures were all moved to online platforms. All the face-to-face meetings, as well as social meeting events, were switched to online video group meetings, which can be accessed easily from everywhere. Knowledge can now be obtained conveniently by anyone that can adapt and utilize all the online resources efficiently. However, a few aspects of academics got affected badly, especially the ones that require face-to-face interaction or physical attendance. Physical labs are one of the things that got struck hard by the social distancing policy. Lab experiments usually require students to physically present to be able to operate lab equipment and record the data to analyze. All the online lab experiment videos defeat the main purpose of a typical real-life physical lab, which is the hands-on aspect. Labs and experiments are some of the best ways for students to learn something new because they let students freely interact with the equipment and gain some hands-on experience that no lectures could provide. The absence of lab experiments in studying is a huge loss for anyone that could not make it to the physical lab experiments.

Fortunately, with the help of Virtual Reality (VR) technology, which is also one of the most upcoming technology, lab experiment is becoming more friendly to online or remote studying. Now instead of coming to a lab section, a student can just put on a VR kit (consists of a headset, two remote controllers, and some other smaller equipment that come with the kit), and now they can attend to a lab section where all of the equipment are interactable. From an article of Adobe about VR Education, it states that *“Virtual reality can be used to enhance student learning and engagement. VR education can transform the way educational content is delivered; it works on the premise of creating a virtual world — real or imagined — and allows users not only see it but also interact with it. Being immersed in what you’re learning motivates you to fully understand it. It’ll require less cognitive load to process the information.”*[1] There is no limit to the development of VR. It makes knowledge more accessible and change the way people normally see and perceived education.

Recent years, with the improvement in high speed computing especially of high resolution graphics and the user interaction devices, the technology of virtual reality has been widely used. VR has emerged as a useful and important tool in today’s society. A VR system creates an environment, which enables human to interact with anything or anyone on a virtual level. In fact, this technology has emerged twenty years ago. Now, VR has been widely applied in the medical field, manufacturing, education, military, gaming, entertainment, commerce, and architecture. VR laboratory is being effectively used for engineering education since the use of VR presents several advantages within the engineering field, including: (1) VR allows simulating in real time the use of otherwise unavailable expensive laboratory equipment; (2) the use of VR avoids potential damages to a real machine caused by students’ misuse during practical classes; (3) VR solves the difficulty of developing practical classes in a real laboratory environment when the groups are overcrowded; (4) VR improves the prevention of occupational hazards; and (5) VR allows the students to interact with complete manufacturing processes, which would be practically impossible in real world [2-4].

This paper focuses mainly on the Solar Energy lab and goes through the development of the lab in a virtual environment. By completing this development, the students will be able to perform lab experiment without coming into a physical lab section. They will be able to interact with the equipment, operate some virtual tools, and collect data for the lab reports. This Solar VR is designed based on the entire lab sections of the Course EET 320 Renewable Energy Systems at Drexel University. This solar lab will consist of four different modules that allow students to learn four factors that will affect the performance of the solar panel. The four modules are:

- The effect of heat on solar panels
- The effect of tilt angle on solar panels
- The effect of shade on solar panels
- The maximum power point of solar panels

The Solar VR lab is designed so that it can be fully functional and replace the actual physical Solar Lab. Students will be able to log in to the lab, perform experiments as a group based on the provided lab instructions, collect all the required data, and work on their lab reports.

II. SCOPE OF THE PROJECT

The main goal of the solar lab is to show students the four important factors that impact the energy output of the solar panel. Therefore, the scope of the project is to implement the modules in the VR solar lab. The first module is the effect of heat on solar panels. In this module, students will expose the solar panel to a heat lamp (heat source) and measure the energy output from the solar panel. Temperature and energy output must be recorded and analyzed [5]. The second module is the effect of tilt angle on the solar panel. In this module, students will be able to interact with the panel as well as the light source. They can adjust the panel's angle as well as change the light angle of the light source. The output energy will be displayed for students to record and analyze later in their lab reports.

The third module is to demonstrate the effect of shade on solar panels. In this module, students will learn how the setup configuration of the solar panel will make difference to the energy output. The different setup will include a parallel setup and a series setup. Students will also learn what happens the energy output when there is shade on the solar panel. The final module is the maximum power point of solar panel. In this experiment, students will observe how the resistance will affect the output power. Through this, they will be able to calculate the maximum power point of the solar panel, the point where the panel produces the most power. Another scope for the project is to make the virtual lab as close to the actual lab as possible and provide a realistic feel for users. Through that, users will be able to grasp the knowledge easier and faster.

III. SETUP THE VR ENVIRONMENT IN UNITY 3D

A. *Setting up a blank workspace*

After the setup and the initialization are finished as shown in Figure 1, a grey and blue blank scene will show that is ready for development [6]. First of all, a plane or a working area needs to be defined with a fixed dimension. The center of this plane will align with the origin of the entire model (at $x = 0$; $y = 0$ and $z = 0$). Later, everything will be built upon this plane. Therefore, this definition is crucial.

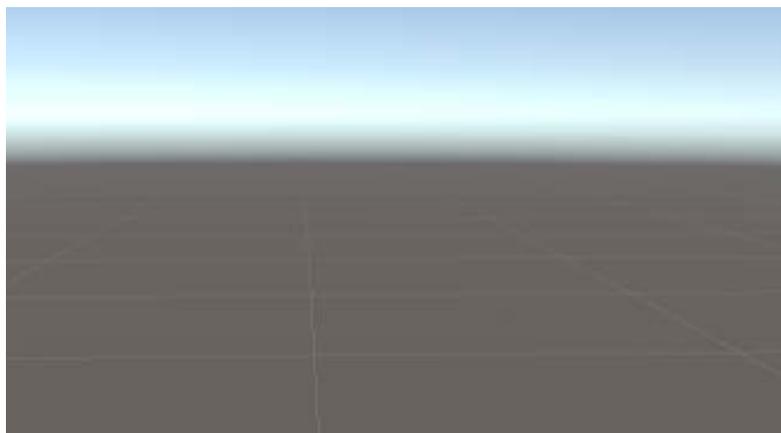


Figure 1: Blank Scene

B. SteamVR Development Kit

Besides installing and setting up a basic environment for Unity 3D like mentioned earlier, installing the SteamVR plugin is a must-have, because it provides many great features which help to speed up and improve the VR development experience. SteamVR provides many features such as interactable properties, circular drives, teleportation, and many other additional models that can be used from the get-go [7]. SteamVR plugin can be acquired for free from the Unity Asset Store.

C. Player Prefab

Prefab is a set of pre-defined and fabricated objects that have certain properties and features. Setting a prefab will allow developers to group a set of multiple items into one object so that it can be managed and organized better. Coming with the SteamVR plugin is the Player Prefab. This Prefab provides all the default configurations for a VR user. This prefab defines many basic properties that a user will have inside the virtual environment, some features being the player's hands, body collider feature, User's view or VR camera. With this prefab in use, some features can be defined, like the virtual images of the user's hands can be defined, how the camera angle will look, or how the user's virtual body will react to objects inside VR. Normally, the player prefab is ready to use immediately without any adjustment.

D. Teleportation and Teleporting area

Navigating around Virtual Environment can be tricky because players are restricted in a small play area (their room) and therefore when playing in a large virtual world, moving around can be hard. Besides that, navigating around using arrow key (like in normal Video Game) will cause Motion Sickness for users if they are not used to interacting within a Virtual Reality environment [8]. The solution for this problem is to use teleportation. Teleportation is a faster and convenient way for users to move around the virtual environment without using the arrow key, or actually moving around their physical space while carrying the VR kits.

At first, a blank thin rectangle panel is used to imitate a solar panel. This panel will have the size of a standard 6×10 cell panels, and therefore will be 65 inch by 39 inch. It is set to floats at a fixed distance above the table surface. The transform position is adjusted to make sure that it can be rotated without having the bottom edge touching the table. In order to make the panel rotatable, a Circular Drive property was set to the rectangle panel. The Axis of rotation was set to be on the x-Axis. The kinematic property is enabled to make sure that the panel will not be under the influence of gravity as well as other collision forces.

A "Canvas" or a display panel is set up right next to the solar panel. This canvas object's main purpose is to display the information related to the panel as it is interacted with. This information will indicate whether the characteristic of the panel was implemented correctly. Information such as the energy output, light angles, panel angle, resistance, and temperature will be displayed on the canvas.

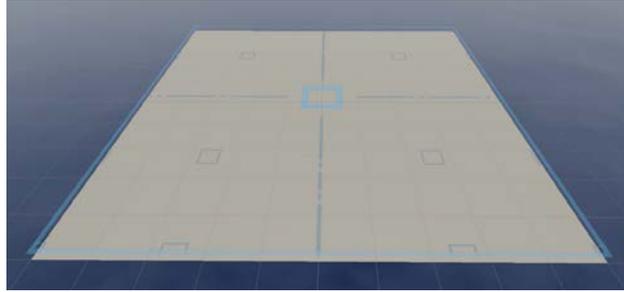


Figure 2: Base Plane and Teleporting Area

A simple lever stick is created and placed on top of the table (Figure 3). This stick will be a controller that controls the position of the sun (light source). In other words, this lever will control the intensity of the light source, as the sun at different angles will produce different light intensities, which, therefore, will affect the input and output energy from the solar panel.

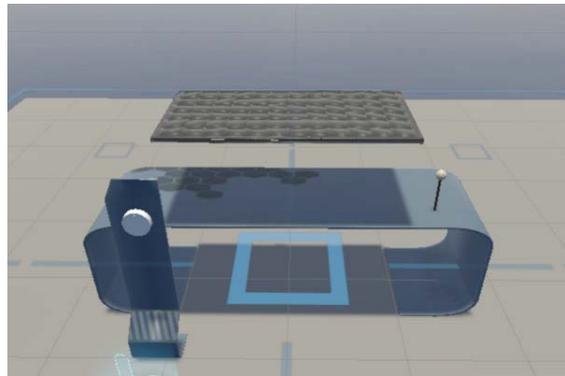


Figure 3: Solar Panel with Components

A simple turning knob is placed right in front of the table in Figure 3. This turning knob will allow users to change the resistance value of the solar panel. The Circular Drive property was implemented to allow users to turn the knob around a selected axis. In this generic model, a small sphere was created to imitate a sun (a source of heat and light for all modules). This sphere is set to float above the panel. The main axis of the sun is offset so that it is aligned with the main origin. This will let the sun moves in a semi-circle movement with a predefined distance (radius) away from the origin in Figure 4.

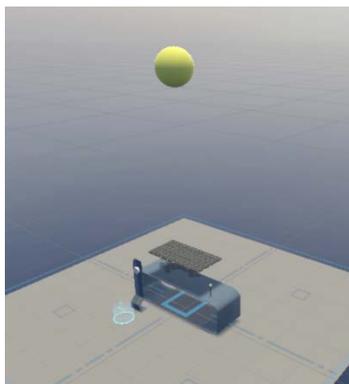


Figure 4: "Light Source" Sphere On Top

V. IMPLEMENTING AND PROGRAMMING THE CHARACTERISTICS FOR EACH OBJECT

A. Basic Interactable Properties

Most of the objects in this module are interactable. In other words, users will be able to touch, grab on, turn, or rotate objects. Therefore, all of the interactable objects must have “Interactable” property. This property is provided with the SteamVR plugin. It also allows users to choose how to interact with the objects, as well as improving user experience when using the objects in a virtual environment. The main characteristic for all objects in this lab model is rotation. For example, the solar panel can rotate around its axis, the lever can be turned around its own origin to change the light source angle, the sun can rotate around the plane’s origin, and finally, the turning knob can rotate around its own center. Therefore, all of the components in this solar lab have the “Circular Drive” property. Basically, the Circular Drive property allows objects to be rotated on a selected axis (either x, y, or z axis). Combining this property with the “Interactable” property, all components can be grabbed and rotated by users.

B. Implementing Temperature change

In order to simulate the temperature in this solar lab module, a script was created and applied to the panel. In general, upon activation (by pressing a button on the table), the temperature value of the solar panel will be raised in time. This characteristic can be done using a programming script in C#. Until the button on the table is turned off, the script will keep on running and increase the temperature value gradually over time.

Currently, there is no general formula that describes the relationship between temperature and output energy. Therefore, it is hard to calculate and output the energy results. In order to solve this problem, multiple real experiments were performed in the physical solar lab. After gathering enough data about the relationship between the energy output and temperature, the energy results were manually inserted into the script. Now, when the script is activated, it will output the energy with the respective temperature matching the real experiments.

Furthermore, to simulate the uncertainties and errors of real experiments, a set of small random coefficients are added to the output energy values. These coefficients need to be small enough to not make any drastic changes to the final calculation and analysis that the students need to perform afterward.

C. Working with angle

As mentioned earlier, most of the components in this lab model are subjected to rotation. However, not all rotation axes are the same. The rotation on the y and z axis are the simplest because there is no special rule applied. The angle can go up to 360 degrees. Working with the angle on the x axis is tricky and tedious because of Gimbal Lock. Gimbal Lock is a feature that Unity enforces on the rotation of a certain axis (the x axis in this case) when using Euler angle system so that the locked angle will never go above 90 degrees or below -90 degrees [9].

In order to avoid Gimbal Lock, quaternion formulas were used instead of the normal Euler angle. Quaternions introduce the fourth attribute to the axis, which is w. “w” is a scalar value that stores the rotation around the vector. Now, instead of rotations around x, y and z axis, the rotations in quaternions are translated into yaw, pitch, and roll, and each rotation is broken down into formulas that using x, y, z and w (Figure 5).

```
x = light.rotation.x;
y = light.rotation.y;
z = light.rotation.z;
w = light.rotation.w;
double yaw = Math.Atan2(2.0 * (y * z + w * x), w * w - x * x - y * y + z * z);
double pitch = Math.Asin(-2.0 * (x * z - w * y));
double roll = Math.Atan2(2.0 * (x * y + w * z), w * w + x * x - y * y - z * z);
```

Figure 5: True Angle from Euler Angle using Quaternions Formulas.

D. Controlling angle

By applying quaternion formulas instead of the usual Euler angle, displaying the rotation angle can be done easily. This concept is implemented for both the panel’s angle as well as the sun’s angle with respected to the center of rotation. For the solar panel, the angle can be adjusted when the user grabs onto the panel and turn it. Its local angle will be recorded and parsed into the angle script as Euler angles. Euler angles will then be converted into Pitch Roll and Yaw using the w scalar and quaternions formula. Finally, the true angle output will be calculated and displayed on the Canvas.

The same angle calculation is applied for the Sun. However, the way the sun’s angle is adjusted is different from the solar panel. In order to change the sun’s angle, the lever will need to be grabbed and turned. The angle of the lever with respect to the table will be matched with the sun’s angle with respect to the plane (or the table). Therefore, the quaternion angle calculation was applied to the lever’s Euler angles to output the true angles, which are then parsed into the transform coordinates of the sun, and thus moves the sun accordingly.

E. Calculate the energy output from the light and panel’s angles.

Unlike the other modules, there is a general formula that can be used to describe the relationship between the tilt angle and the energy output of the solar panels. The following is the formula for calculating the energy output [10].

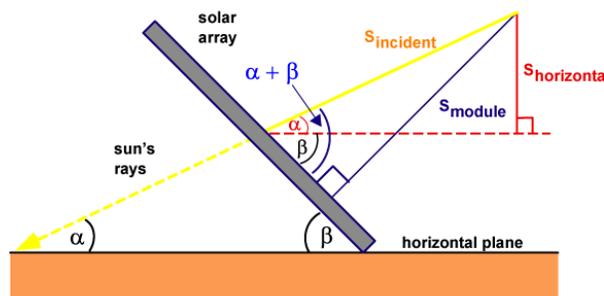


Figure 6: Effect of Tilt Angle and Sun Elevation (picture from pveduction.org)

$$\text{Energy Output} = \text{Panel Area} \times \text{effeciency} \times \text{Solar Radiation} \quad (1)$$

As mentioned earlier, the size of the solar panel is 65 inch \times 39 inch, which yields a surface area of 2535 square inches. The efficiency is varied with the material of the solar panel. For this lab, the solar panel is assumed to be a monocrystalline model. Therefore, the efficiency is equal to 16% or 0.16. The Solar Radiation can be calculated as followed [10]:

$$S_{\text{module}} = \sin(\alpha + \beta) \times \sin(\alpha) \times S_{\text{horizontal}} \quad (2)$$

From the formula, α is sun elevation angle, and β is panel tilt angle. $S_{\text{horizontal}}$ is the sun radiation when the solar panel is at a horizontal level and the sun or α is at a 90-degree angle (directly on top). $S_{\text{horizontal}}$ is equaled to 5.27 (Figure 6). By using the formula above, with the current panel's tilt angle and the sun's angle, the theoretical energy output can be calculated and displayed on the Canvas. However, just like other modules, a small random error coefficient will be applied to the final energy output results to simulate the uncertainty of the equipment.

F. Controlling the resistance value

According to the physical Solar lab, there are nine different resistance values that the resistor can have ranging from 0.1 Ohm to infinity Ohm. These values are assigned to each angle range of the turning knob. For example, the value of the resistor is 0.1 ohm when the knob is turned with an angle between 0 to 36 degrees, then 0.33 Ohm in the range of 37 to 72 degrees, etc. Because the knob is rotated in the y-axis, therefore, Euler angle can be used directly without worrying about the gimbal lock. Energy output calculation for this module will use the same approach as the implementation of the temperature changes. The real lab results will be gathered and implemented into the script with some error coefficients. Different energy output will be displayed out on the Canvas as the resistor value changes. Through results collection and analysis, students will be able to find the MPP.

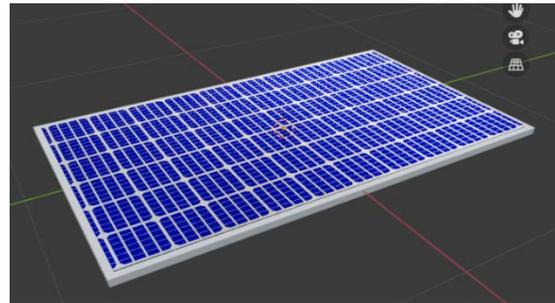
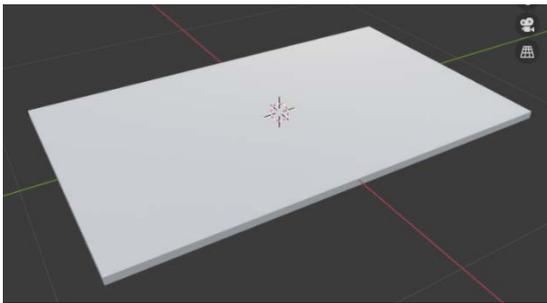


Figure 7: Blank Panel, Rendered by Blender Figure 8: Rendered Panel with Solar Cell Pattern

VI. DESIGNING THE 3D MODEL WITH BLENDER AND AUTODESK 3DS MAX

In order to make the solar panel looks more realistic, Blender was used to redesign the solar panel and to give it a more realistic look [11]. First of all, a thin rectangle box with the same size as the panel in unity is drawn up. After that, the typical solar panel's "grid" pattern was designed

and implement into the rectangle box in Figure 7. Finally, a realistic look yet simple solar panel is created in Figure 8.

The sun is no longer a light source in the actual lab modules as it is unrealistic to have adjustable sunlight inside of the virtual lab room. Therefore, the sun will be replaced with a heat lamp that is placed on top of the room ceiling. The heat lamp will act virtually as both light source and heat source for the solar panel underneath. The light is modeled and created using Autodesk 3ds MAX in Figure 9. This model is then exported as an MTL file and imported into Unity as a prefab object.

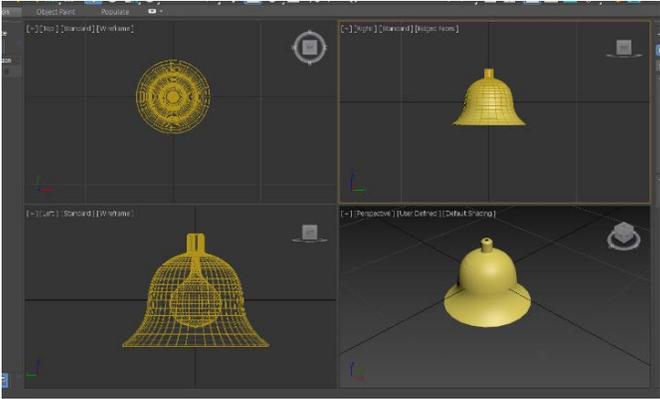


Figure 9: Heat Lamp Shaped and Modelled with Autodesk 3ds MAX [12]

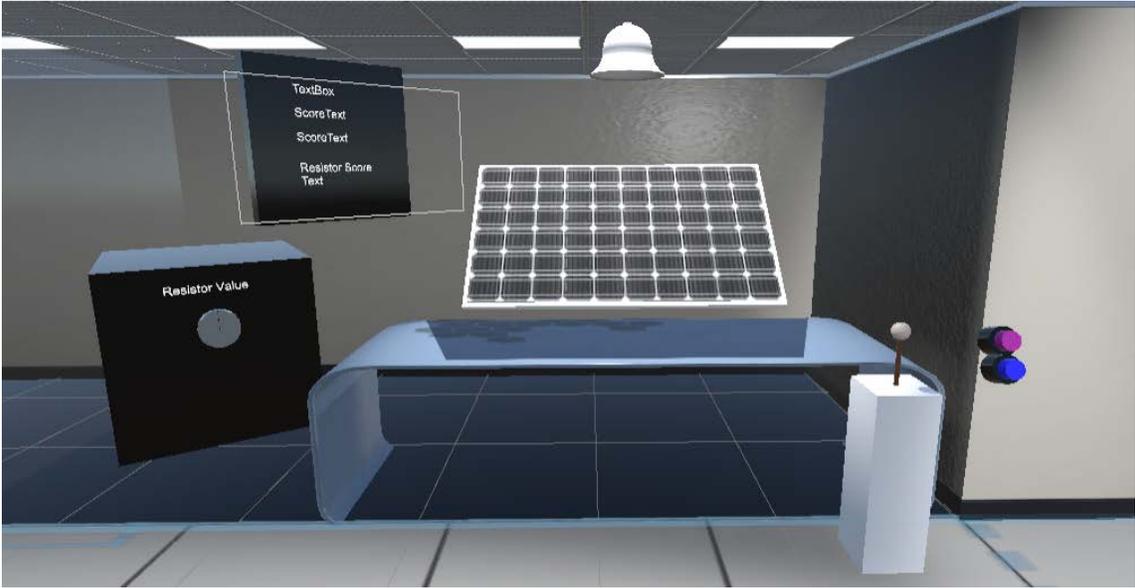


Figure 10: Solar Lab Modules Placed in the VR Energy Lab

VII. RESULTS

After the solar module is completed with fully implemented scripts, the whole module will be migrated into the official VR Renewable Energy lab room, where other energy modules are

presented and displayed. The blank solar panel from the beginning is now replaced with a rendered version. The sun is replaced by the heat lamp which is mounted on the ceiling of the lab room, right above the solar panel. Now instead of having a sun rotation around a fixed origin, the lamp will be rotated on its mount as the lever is adjusted. There will be multiple buttons displayed in front of the solar module which allow users to switch between different lab modules. And finally, the Canvas on the wall will display all the necessary information about the panel (Figure 10).

VIII. CONCLUSIONS

With the help of one of the most upcoming and growing technology - Virtual Reality – a realistic and functional Solar Energy Virtual Reality Lab can be developed and implemented. Even though at this stage of the development, the Solar Modules is still simple, not completely stable, and fully functional yet as some of the more advanced features like notetaking and data recording are not fully implemented, this solar lab can be used as a replacement for the physical Solar Energy lab. This indeed has satisfied the overall scope of the project, which was defined at the beginning of this paper. This lab will be the first step and a strong basis for future development and improvement. In the future, there will be more features added to this module to improve user experience and enhance the realistic feel for students.

ACKNOWLEDGEMENT

This work has been supported by the US Department of Education under the joint MSEIP Program with the University of Texas at El Paso, PR/Award No.: P120A180101. The authors wish to express sincere gratitude for their financial support.

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