

Creating Open Source Repository of 3D Models of Laboratory Equipments using Blender

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Abstract—Laboratory experiments provide hands on experience to students, thereby enhancing their understanding of the given topic. Often, due to lack of resources, interactive simulations of laboratory experiments are an attractive substitute. Simulations could be two dimensional (2D) or they could be three dimensional (3D). 3D has added advantages of multiple viewing angles, more realistic views with textures and lights, and cross-section walk-through.

The process of creating a 3D simulation for a lab experiment is time consuming. Typically, it has 3 stages: Modeling, Animation and Adding Interactivity. We believe that a significant amount of time, money and effort could be saved if a repository of 3D models created using some Open Source software (such as Blender) is available. This will allow animators and programmers to concentrate on the further stages.

In this paper we have identified the key design goals and presented a methodology to create a repository of 3D models. We have used this methodology to create more than 40 models in Blender, in about 4 months. These models can be downloaded and directly used by anyone. Moreover others can use this methodology to create their own model repository.

Keywords- 3D animation repositories; Content creation methodologies; Open Source content.

I. INTRODUCTION

It is well known that laboratory experiments provide hands on experience to students, thereby enhancing their understanding of the given topic. However, well-equipped laboratories are not available in many universities, especially in developing countries, due to the expenses involved in terms of infrastructure setup, trained manpower and maintenance.

So, simulations of laboratory experiments are an attractive substitute. Simulations are not only reusable and accessible to large numbers of users, but also can be maintained, modified or upgraded with minimal resources. When such simulations have sufficient interactivity and user control, they can be a close approximation to performing the experiment in a real-life laboratory [1]. As an added advantage, simulations could even go a step further and allow user to experiment with parameter values that cannot be done in a real-life laboratory. For example, in a simulation of electric circuit, the value of the current can be increased to levels that would be dangerous in a real-life experiment. Hence it is desirable to build a repository of simulations of laboratory experiments.

These simulations could be two dimensional (2D) and built using tools such as Flash, Java, or they could be three dimensional (3D) and built using tools such as 3-D Max, Blender. Often 3D simulations of laboratory experiments offers more facilities to the user, as compared to 2D. For example, multiple viewing angles, more realistic views with textures and lights, and cross-section walk-through, etc. Hence it is desirable to create 3D simulations for lab experiments. These could be of two types: (i) Simulations - Visualizations having user-driven interactivity and (ii) Animations - Visualizations without user-control. Both these types could be created using 3D animation software.

There are many 3D animation software available. Most of these, such as 3-D Max and Maya, are proprietary. The usefulness of the experiments built using such software is limited to those colleges that can afford them. On the other hand, 3D simulations/animations built using Open Source tools, such as Blender, can be more widely disseminated, have scope for customization by users, etc. In general, using Blender gives us all the advantages of any Open Source software [2].

The process of creating a 3D simulation for a lab experiment is time consuming. Typically, it has 3 stages: Modeling, Animation and Adding Interactivity. One way to reduce the overall time taken would be to pipeline these stages, using people who specialize in each stage. So a Modeler would go on creating models, which can be input to an Animator, thereby gaining the standard advantages of pipelining [3].

Another way to reduce the overall time taken to create 3D simulations is to build a repository of commonly used models. This is more useful than even the pipelining strategy, since the time taken to create the Model need not be considered as part of the development effort. Animators and Programmers can incorporate readily available models and concentrate on the further stages of developing the simulation. Hence we believe that it would be useful to create a repository of models of laboratory equipment. Moreover, if these models are created using open source software, their usefulness is further increased.

In this paper, we present a methodology to create a repository of 3D models. Using Blender as the open source software, we have created 40 models of laboratory equipment, in about 4 months. Our key contributions are: (i)

A repository of models that could be downloaded and directly used by anyone, (ii) Identification of key design goals that should be met by any such model repository and (iii) A well-defined methodology for creating the repository, in line with the design goals. As a result, anyone can use this methodology to create their own model repository and/or contribute to our/other open source efforts.

In section II, we give the background on 3D modeling process. In section III, we present the key design goals identified and an overview of the methodology in section IV. Our detailed methodology is discussed in section V. In section VI, we show examples that validate how our methodology meets the design goals. We conclude with directions of our future work in section VII.

II. BACKGROUND

Scientific visualization has the potential to make science education more accessible [4]. Students often find it difficult to conceptualize the scientific diagrams of the experiments in the textbooks. Animation provides the ability to add motion to these static diagrams. Positive learning effects of animation have been seen in many areas like Physics, Microbiology and Mathematics [5].

Two dimensional (2D) animation is widely prevalent, and has been shown to be successful in many areas [6]. It also has its own limitations mainly regarding the visualization possibilities of showing the depth of the objects apart from the length and breadth. Advent of three dimensional (3D) animation has expanded the possibilities and scope of the content in many ways especially for the laboratory experiments. 3D animation not only continues to have the advantages offered by 2D, like interactivity and reusability, but also adds a whole new dimension of visualization possibilities. It makes it feasible to go beyond the flat view and see the experiments from multiple angles [7]. For example: Internal organs of human body right up to micro/nano level of DNA strands, walk through of a solar system and cross sections of mechanical engine. We focus on creating repository of 3D models for animation in this paper.

A. Advantages of 3D Animation repositories

Access to 3D animation, especially for educational content is increasing. Availability and accessibility of animation is an important area to be looked at. Instructors today, plan to use animated content in classrooms, but often don't have time to create it themselves. The web search of animation is often time consuming. Problem faced by the users is typically of the filtering of the content. It becomes a huge task to weed out the unnecessary links, and pages where the required animation is not present. A collection with a specific categorization as per the domains, may be preferable option. A repository is a collection of resources that can be accessed to retrieve information [9]. 3D animation repositories could be one of the options to solve the problems mentioned above.

B. Process of creating 3D animation

The process of animation production is typically split in three stages. These are (i) modeling, (ii) animation and (iii) adding interactivity. These stages are dependent on each other, and need artists/developers with specific skill sets respectively. For example: Modelers focus on the 3D look and feel of the mesh, and animators, mainly concentrate on the motion of those models. Further to this, when it comes to adding interactivity, a new skill set is required such as scripting. This makes the process resource intensive in terms of man power as well as hardware/software required. In such conditions online repositories of animation are likely to be useful.

Repositories can have a collection of 3D models, in a format that can be used by any 3D software. The users can then use the 3D models and create their own animation or interactivity as per their requirement. We have seen that there can be multiple experiments using the same apparatus. For example: Resistance box is used in the experiment explaining Ohm's law, and also in the experiment to determine the internal resistance of a cell by using a potentiometer. If models are readily available, then the total time for production of 3D content will reduce as illustrated below.

We have considered three different approaches of creating three animations for laboratory experiment. The first approach is Monolithic approach. Here the animator starts from modeling and creates animations. Other approach is Modular pipeline approach where a team of three (an animator, a modeler, a programmer) starts their tasks one by one, that is when the modeler finish modeling animator starts its animation and after the animation is completed interactivity is added to the animation by programmer. Third approach is where two persons (an animator and a programmer) make use of the models that are already created for creating the same three animations. It is assumed that teams in all the approaches have undergone basic training in an appropriate 3D animation software.

Consider an experiment of Ohm's law from High school Physics curriculum. This experiment has 6 objects (Resistance box, Voltmeter, Milli ammeter, Battery, Rheostat and Connecting wires).

For a modeler it takes 2 days (5 hrs a day) that is 10 hrs to create a 3D model of an object of above mentioned experiment. Considering the complexity of the objects on an average it will take 12 days that is (12X5) 60 hrs to model these six objects. After this an animator will take maximum 6 days (6X5) 30 hrs to animate the experiment. Further a programmer will need 2 days that is (2X5) 10 hrs. Hence, it takes 100 hrs to create animation.

TABLE I. MONOLITHIC APPROACH FOR 1 PERSON

Monolithic Approach 1 person	M1	A1	I1	M2	A2	I2	M3	A3	I3
	60	30	10	60	30	10	60	30	10
Total: 300 hrs consumed									

TABLE II. MODULAR PIPELINE APPROACH INCLUDING A MODELER, A ANIMATOR AND A PROGRAMMER

Modular Pipeline Approach 1 modeler, 1 animator and 1 programmer	M1		M2		M3		Modeling task over	
			A1		A2		A3	
				I1		I2		I3
	60		60		60		30	10
Total: 220 hrs consumed								

TABLE III. CREATING ANIMATION BY USING 3D MODELS REPOSITORY

Making use of Repository 1 animator and 1 programmer	A1		A2		A3		Animation task over	
			I1		I2		I3	
	30		30		30		10	
	Total: 100 hrs consumed							

Table I shows that an animator completes an animation in 100 hours, that is for 3 animations **300 hours are needed**. Table II shows a modular approach where as the modeling is finished the animator starts his task, simultaneously the modeler starts with the next task. Due to overlap of tasks, time is saved. It can be seen that by this approach **220 hours** are needed to animate the same 3 animations. Table III shows the tasks performed using a 3D models repository. Here the process starts with animation directly. Thus there are only two steps to be performed, that is, animation and adding interactivity. The total time consumed is **100 hours**.

The above tables show that making use of the repository saves about 200 hours of time. Moreover manpower is reduced in this approach. In the rest of the paper we present a methodology for creating 3D models repository.

III. DESIGN GOALS

Our solution is to create 3D models repositories. We have identified the following design goals:

A. Providing 3D models that are functionally correct

Our design goal is to create functional models. Functionality is the capability of an object to serve the purpose it is designed for. For example a beaker holds liquid. The thimble of a screw gauge can be rotated to move the spindle. The details are described in sections V-B-2 (Checking functionality) and V-C-3 (Final checking of functionality).

B. Providing Realistic 3D models

Models created should be as close to reality as possible, that is, the visual look and feel of the model should be similar to the actual object. The realism of the models will enhance the experience of the end users. Example: Beaker made of glass, Vernier calipers made of steel or resistance box made of wood and cast iron etc. The steps mentioned in

the section V-C-1 (Texturing) are useful in achieving this design goal.

C. Providing Accurate 3D models of apparatus

Accuracy corresponds to the realism of the model but also has an added attribute of correct measurements. An inaccurate model may not function properly. Ex: The measurement markings shown on the model (beaker) should not have errors. A set of steps in the content creation methodology ensures meeting this design goal. The details of these steps are discussed in the sections V-B-1-i (Test rendering), and V-C-1 (Texturing).

D. Providing 3D models that can be rendered quickly

Rendering is a CPU- intensive process. In this process the CPU calculates individual pixels for each frame based on models, materials, lighting, and effects [10]. Increase in number of vertices increases the load on CPU. As the number of vertices increase, load on CPU increases. Hence it takes more time to display the graphics and motion. As a result, the size of files increase. Further, at the time of actual animation many similar objects are created and imported in a single file, as a result load on CPU shoots up. This results in slow performance of the computer. This can be avoided by following the step in V-B-3 (Optimizing the mesh).

E. Providing 3D models which are reusable

Recreating a model of an object for each experiment every time is a time consuming process. Our goal is to create models that can be reused in many experiments, without any modifications to the model. For example: a resistance box model can be used as it is in more than one experiment, such as Ohm's Law and Potentiometer. For detailed description, please refer section VI-E (Ease of reusability).

F. Providing 3D models which are extensible

In some cases, a model has to be customized to suit the requirement. This goal is to create models that can be modified as per requirements. For example: modification of a beaker of 100ml to 500ml. This cannot be merely done by scaling it and changing its texture map having new markings. It also involves change of the glass thickness. Detailed description of how do we ensure that the model becomes extensible easily, can be seen in section VI-F (Ease of extensibility).

G. Creating 3D models with low production cost

The cost of 3D production is higher, mainly because of the hardware and software required. The hardware requirement is inevitable, but the licensing cost of the software can be reduced if Open Source software is used. We use Blender, which is a free open source 3D content creation suite, available for all major operating systems under the GNU General Public License [11]. It supports a variety of geometric primitives including polygon meshes and fast subdivision surface modeling. It has advanced tools for key framed animation, including inverse kinematics and armature (skeletal).

It also has a game engine for adding interactivity to the animations. Currently, Blender has been used in different entertainment domains like animated movies, short films, television commercials, and gaming [12]. As Blender is a free software, we plan to utilize this aspect and release the models created in Blender, in Open Source (OS) domain. We show validation examples of the design goals explained above in the section VI (Validation of Methodology).

IV. METHODOLOGY

Our content creation methodology is derived from standard 3D content creation process for entertainment domain. This typically comprises of: (1) Pre-production (ideation), (2) Production (actual creation), and (3) Post-production (output creation in various suitable formats). We refer to the Production process (2) in this paper. We have changed some steps of that to suit our requirement. “Fig. 1” shows the 3D animation process for production stage of entertainment domain. “Fig. 2” explains our process, which is divided into four main stages:

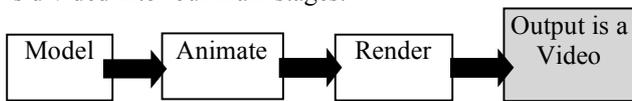


Figure 1. 3D animation process for production stage of entertainment domain / movies

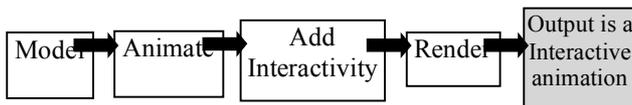


Figure 2. 3D animation process for production stage of educational content

The details of Modeling phase of the content creation of educational content is explained in “Table IV” given below:

TABLE IV: MODELING PHASE IN 3D ANIMATION (EDUCATIONAL CONTENT)

Process of 3D animation	Stages of Modeling	Steps involved
Model ↓ Animate ↓ Add Interactivity ↓ Render ↓ Output is a Interactive animation	Pre Modeling	Survey of images Manipulation of images
	Modeling	Modeling Functionality Optimization
	Post Modeling	Texturing Lighting Check for functionality and optimization Packing

A. Our 3D animation process in detail

1) *Modeling*: 3D modeling is the process of developing a mathematical, wireframe representation of a three-dimensional object. This requires accuracy, and details of the object selected. Model is made up of units called vertices, faces and edges. Texturing and lighting are two internal stages of modeling. The details of the two sub-steps are:

a) *Texturing*: Texturing is the process of applying a bitmap image to the surface of a model. This gives a realistic look to the model

b) *Lighting*: Illuminating the object, and the scene containing the object using various light sources.

2) *Animation*: The process of adding motion to the static models created is animation. This also includes various other motion aspects like collision, fluids etc.

3) *Adding Interactivity*: In this sub step, the animation of the 3D models is added with interactivity options. These can be in the form of buttons, sliders, select and drop, or regulators.

4) *Rendering*: This sub step generates an image out of a scene description (of geometry, lights, material and camera details) [13]. Creating a integrated file having all the necessary components used, is also an important output of this step. Details of this sub step are described in section V-C-4 (Packing).

In the “Fig. 3”, we have explained the process of phase 1, Modeling in detail. We adapt standard software engineering principles like ‘the waterfall model’ and the 3D animation processes used in the entertainment domain [14]. The Modeling phase is further divided in 3 stages. They are (a) Pre Modeling, (b) Modeling, and (c) Post Modeling.

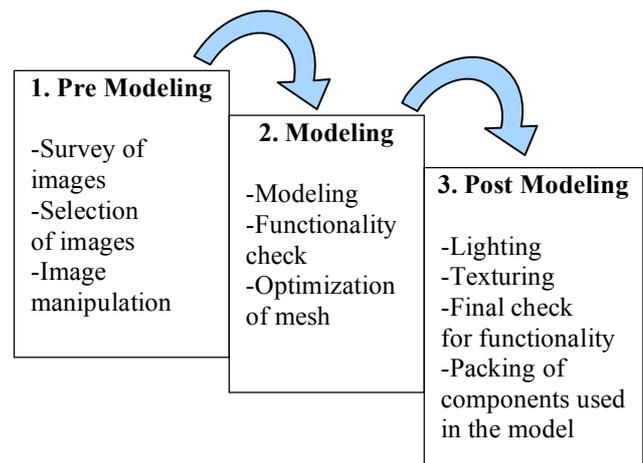


Figure 3. Details of the Modeling process

V. DETAILED MODELING PROCESS

A. Pre modeling stage:

Prior to the modeling stage, the modeling artist requires sufficient data to create a mesh/model. This information can be in the form of images, videos, or even actual handling of the objects. Following are the steps that are followed:

1) Survey of images:

Take photographs of the actual object from various angles (like top, front and side). Collect images of the same object from various resources like web, books, CD ROMs etc. Depending on their clarity select the image to be used as reference. Clarity here refers to the outline of the image, as this is useful while modeling.

2) Manipulation of images selected:

If the images available do not show clear outline of the object, make use of an image editing software to make the outline of the images clear. Place the multiple angles shot by



the cameras proportionally and label with appropriate information (as shown in the “Fig. 4”). Pass these labeled images having a clear outline of the object to the next stage where the actual modeling starts.

Figure 4. Beaker photographs showing various angles

B. Modeling:

This step has the actual modeling step along with the checking of the basic functionality and also some steps to optimize the mesh.

1) Modeling:

Once the images are approved, creation of 3D model starts. Images selected in above phase are used as background image for 3D modeling. These models are created using basic shapes as follows:

- Use the reference image created in the step A.2, to start the modeling. For example see Fig. 4. This has various viewing angles of the object like: Top, Bottom and Side.
- Start with available basic shapes like square, circle rectangle etc. See Fig. 5.
- Add mesh (vertices, faces and edges) to the basic shape using various transformations. See “Fig. 5”.

a) Compare the model with the reference image, to check whether the shape of the model created matches with the image. Compare not only from a single viewing angle, but multiple viewing angles. It is advisable to refer actual object, and get a feel for it by handling it. See “Fig. 5”.

e) Label the objects using a convenient naming scheme, to make it easy for locating them. Example: Base of resistance box, Shaft on the right, Shaft on the left etc. This naming would be highly useful at the time of adding textures and materials, animation, and rigging. See Fig. 6.

f) Use 'layers' to place objects and avoid clutter while modeling is on.

g) Name the layers appropriately, to avoid confusion.

h) Name the file clearly by following certain pattern for easy identification of files. Try to avoid names like: box_new11.blend, box_new_111.blend etc.

i) Test render at relevant stages, to check for accuracy of model in comparison with the provided image.

Model movable and non-movable parts of the apparatus separately. This will be helpful in adding motion to the relevant parts without moving the other ones

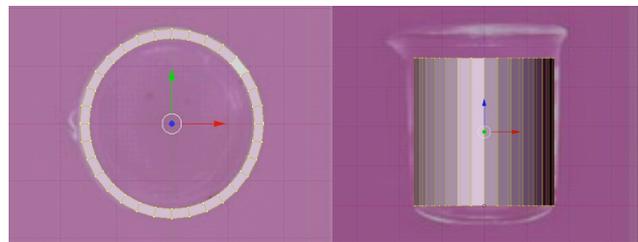


Figure 5. Starting steps of modeling using basic shapes with the help of reference image in the background

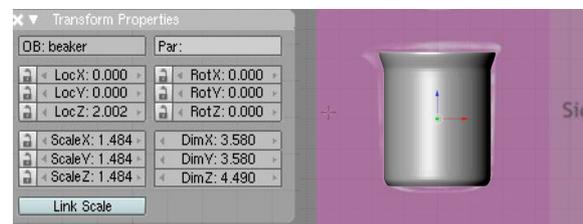


Figure 6. Labeling of the mesh

2) Checking functionality:

Functionality is the capability of an object to serve the purpose it is designed for. In this step it is checked whether the model can perform its function properly. This is done as follows:

- The movable parts, or the parts with pre-assigned functions are checked within the boundary limits.
- The parts which cannot function properly, are sent back to step B-1 for re-modeling.
- The correct objects are sent ahead to the next step of optimizing the mesh.

3) Optimizing the mesh:

After a functional model is created it undergoes a check for optimization. Models created consist of vertices. It is important to check that the model doesn't have vertices that

do not affect the shape of the object. More/undesired number of vertices would lead to increase in the file size and render time. If the model has more vertices than required, that is those vertices that do not affect the shape of the object then the modeling artist reduces the number of vertices to an appropriate and necessary level using some options like:

- a) Removing doubles: In creation of objects where the mesh starts/ends, there could be multiple end/start vertices. This can be rectified by removing the duplicate vertices and reducing the number.
- b) Removing Edge loops: Modifiers like Sub-Surf, and Sub-Divide are often added for offering a smoother finish to the model. This typically increases the number of vertices exponentially. It is a popular feature to remove the vertices on the edge loop of all the edges where the model has 2 points in a straight line. See Fig. 11.

A functional and optimized model is created at the end of the production stage.

C. Post modeling:

After the modeling is over the model is textured and illuminated for achieving a realistic look. The final functionality check endorses a correct model, and it is rendered in a compatible format by packing all the necessary components along with.

1) Texturing:

Textures are applied to specify the properties of an object. For example a beaker should have a glass texture, that is, it should be transparent, it should have a shiny surface etc. This brings realism in the model. This makes it easier to identify with what kind of material is it made up of. Ready made textures available on web or specific textures as per the requirement are created.

- a) Textures are selected carefully to match the exact colour, pattern, or the surface of the object. See Fig. 7.
- b) Various techniques like bump mapping are used to achieve maximum realistic look.
- c) Naming of textures is important, it will facilitate in the situation where the model is customized by other users. See Fig. 7.
- d) The texture maps used for the markings on the scientific apparatus are created with maximum details to avoid errors.

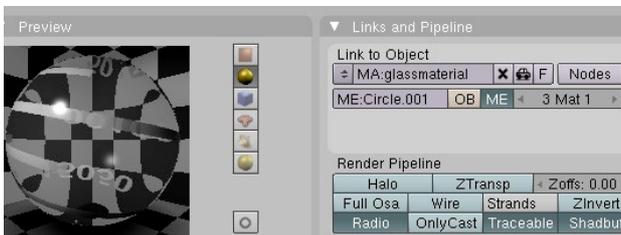


Figure 7. Texturing the mesh and labeling the texture

2) Lighting:

After the texturing lights are added to the model in order to make the 3D model clearly visible. Extra care is taken while

lighting up glassware as the reflections and refractions may create visual disturbance.

- a) Various types of lights are used to achieve specific visual effects. These include sun (for omni /global light), spot (with a possibility to focus on a specific area), etc. Lights can also have colours to add the visual quality.
- b) The lights are typically saved on layers, so that when the integration of the apparatus is done, the same lights can be placed appropriately.

3) Final check of the functionality and optimization:

After the model is complete in all aspects including lighting and texturing, one final check is performed for functionality. This is to make sure that after the preliminary functionality check, the subsequent steps haven't disturbed the modeling. The model is then also checked for the optimization of the mesh, vertices, textures etc. before the last stage of packing. This corresponds to the system testing phase in software engineering [25].

4) Packing:

All the associated files of the model, like textures, lights, materials etc are important, especially as the model we have created is to be uploaded to a repository.

- a) Absence of any of these can lead to a incorrect display of the model. Necessary precautions are taken to pack the file.
- b) This also important where the model is supposed to be extensible. In which case the availability of all the components required for the model are available at one place.

VI. VALIDATION OF METHODOLOGY VIS A VIS DESIGN GOALS

We have identified a set of design goals which are necessary for creating a repository. In this section we show examples which validate each of the design goals discussed in section III. We have various examples from our repository which can illustrate application of a particular design goal.

A. Example showing the functionality of model

As discussed earlier, every object when created is designed such that it is capable of serving the purpose it is created for. One such example is a vernier caliper. It is used to measure the size of an object. A 3D model of a vernier caliper should be able to offer similar function. For example: The auxiliary scale should be movable over the main scale.

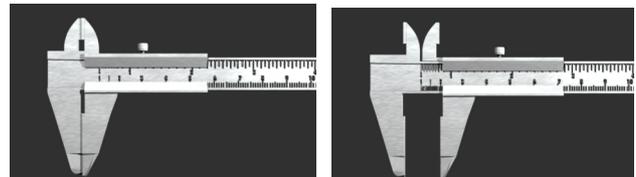


Figure 8. Vernier caliper modeled using Blender

B. Example of realistic 3D models

Models created should be close to reality. For example the beaker / measuring cylinder used in laboratory has marking scheme on it that makes the measurement of the contents inside easier. Models in our repository have marking scheme on it.

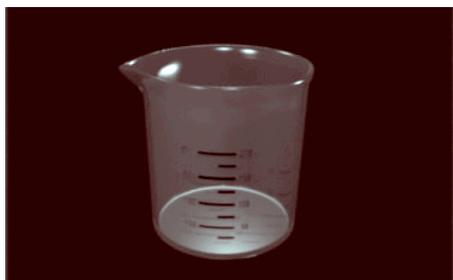


Figure 9. Beaker modeled using Blender

C. Example showing accuracy in our models

Accuracy corresponds to the realism of the model but also has an added attribute of correct measurements. Accuracy is state where we say the model is error free. This is one of the necessary feature that a 3D model created for educational domain should necessarily posses.

For example if 3D model of a beaker has the loop of vertices of inner layer of beaker open at the base of beaker, it will cause a problem while using it in an animation. If liquid is poured inside the beaker, it will enter into the gap inside the layers of beaker, that is it will fill up the thickness of beaker. Which is very incorrect thing to happen. So accuracy in model is very necessary. The black arrow in the image below, shows the open area in the mesh.

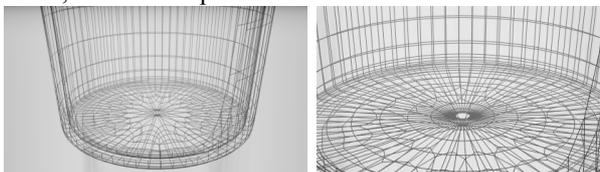


Figure 10. 3D model of a beaker showing open mesh at the base

D. Optimization of the mesh

From the Fig. 11, the conical flask on the right has less vertices than the left one. In the rendered image, the difference is not visible. The technique discussed in 2.3.a of deleting the edge loops is instrumental for this change. This makes the mesh lighter in terms of the vertices used. As long as we consider one model at a time it is feasible to ignore the number of vertices. But ultimately when animation of an experiment will be created it will include more than one model. Rendering is very CPU intensive and complex animations can take days to render, even when spreading the work over multiple computers [10].

If optimization is not performed the final animation can take hours to render. It may happen that the system cannot bear the load and may not function properly.

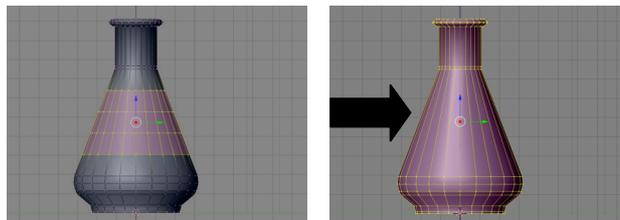


Figure 11. Reduced number of vertices in the beaker model

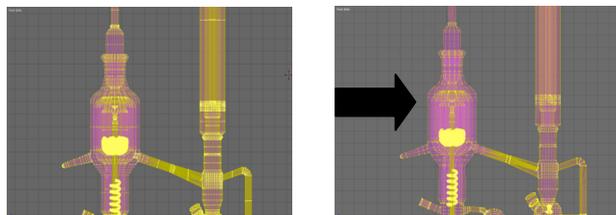


Figure 12. Reduced number of vertices in the VLE model

E. Ease of Reusability

Recreating a model of an object for each experiment every time is a time consuming process. Our goal is to provide models that can be reused in many experiments. For example resistance box can be used in more than one experiments that is Ohm's Law and Potentiometer. See Figs. 13, 14.



Resistance Box

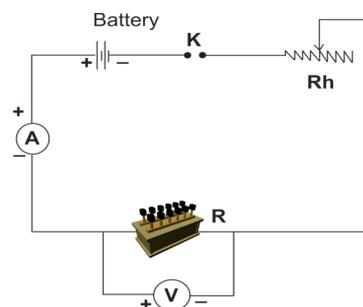


Figure 13. Circuit diagram for experiment to verify Ohm's Law.

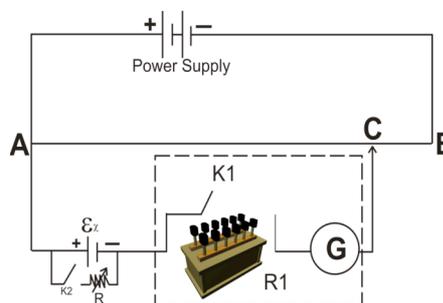


Figure 14. Circuit diagram for experiment to determine the internal resistance of a cell by using a potentiometer.

F. Ease of Extensibility

Our goal is to provide a facility to customize models. Models created should be having a facility of modifying as per the user requirements. For example a beaker of 100ml can be modified to 500ml beaker by scaling it and changing its marking scheme.



Figure 15. Showing the extensibility of use

VII. CONCLUSIONS

In summary, this paper has shown that it is worthwhile to create a repository of 3D models using a well defined methodology. This repository is very useful for animators as it saves the time of creating models as well as manpower.

Basic Blender knowledge is necessary to make use of our 3D model repository. Some experiments that require high precision models may require customized model. For example lab experiment of VLE is part of the curriculum for the undergraduate lab in Chemical engineering [15]. The apparatus for this experiment has many sub parts like the vacuum jacket, mixing spiral, etc are rarely used in any other experiment. In such cases it would be better to create the model from scratch as understanding and customizing models would be a time consuming task.

Our key contributions are: (i) A repository of models that could be downloaded and directly used by anyone, (ii) Identification of key design goals that should be met by any such model repository and (iii) A well-defined methodology for creating the repository, in line with the design goals. As a result, anyone can use this methodology to create their own model repository and/or contribute to our/other open source efforts. We have created models for experiments in Physics and Chemistry domain which are available at <http://oscar.iitb.ac.in/blenderrepository.do>. An Engineering student has used these models to create an animation explaining Ohm's Law which can be seen at <http://oscar.iitb.ac.in/blenderrepository/ohmslaw.do>. "Fig. 12" shows a screen capture from that animation. He is also using the same to create the animation of Potentiometer.

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