

Use 3D Graphics Learning Environment to Help Students Comprehend Non-Intuitive Science Concepts

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Abstract

Comprehending complex, abstract and non-intuitive concepts is always a challenging and unavoidable task for science and engineering students. Mastery of abstract concepts requires students to build mental models about phenomena that often must incorporate invisible factors that represent intangible concepts, items, and abstractions. 3D graphics learning environment uses 3D technologies to allow the creation, simulation, and visualization of 3D representations of abstract data, events, and concepts that have no physical form in the real physical world. It lets students interact with the 3D models, manipulate relevant parameters, and take on different points of view in real-time. Through 3D graphics learning environment, students can be immersed within any non-existing phenomenon visually, auditory, and haptically, thus helping them to comprehend the abstract data or concepts deeply and intuitively. In this article, we discuss the features, power, and educational use of 3D graphics learning environment. We also present several use cases of using 3D graphics learning systems for teaching and learning in classrooms at Prairie View A&M University.

Introduction

Scientific literacy -- the capability to understand the interrelationships among the natural world, technology, and science, and to apply scientific knowledge and skills to personal decision-making and the analysis of societal issues -- is a major goal for education in the 21st century. To achieve scientific literacy, students must interact with scientific objects and data and must experience the role of interpretation and analysis in resolving

problems.[1] One unavoidable task that students must face is to understand many complex, abstract, and non-intuitive concepts. Given the constraints of traditional classroom settings, laboratory experiments are sometimes difficult, even impossible, to conduct due to the lack of equipment and safety issues.

3D graphics learning systems can provide an intriguing potential complement to the real world and laboratory settings, enabling students to explore simulated situations, formulate the underlying causes of problems, conduct investigations, analyze data, and learn from animation systems. Such learning systems provide a common context to realize the unique capabilities of sophisticated computers for enhancing learning, such as utilizing modeling and visualization as powerful means of bridging between experience and abstraction.

This article addresses the features, power, and educational use of 3D graphics learning environment. Several use cases of using such systems for teaching and learning in classrooms at Prairie View A&M University are presented.

The features and power of 3D graphics learning systems

3D graphics learning systems are capable of offering teachers and students unique experiences that cannot be achieved in the real world.[2,4,5] The abilities listed below make 3D graphics learning systems distinguished educational tools.

3D graphics learning systems help learners understand complex, abstract, and non-intuitive concepts and systems. The ability to work with abstract and multidimensional phenomena that

people usually have difficulty comprehending is a crucial skill in today's society, not only in the academic world but also for large parts of the workforce as a whole. For many educational situations, it is important and useful to find ways to help learners recognize patterns, qualitatively understand physical processes, move among different frames of reference, and more easily control dynamic models that may contain intangible information. Mastery of abstract concepts requires learners to build mental models about phenomena that often must incorporate invisible factors that represent intangible concepts, items, and abstractions. Traditional methods of displaying and visualizing these abstract concepts on computer screens or in books are two-dimensional to their nature, even though they seek to describe a reality that is often three-dimensional. 3D graphics systems use 3D graphics and simulation technologies to allow the creation, simulation, and visualization of 3D representations of abstract data, events, and concepts that have no physical form in the real physical world. Furthermore, 3D graphics learning systems also allow learners to interact with the 3D models, manipulate relevant parameters, and take on different points of view in real-time. Through 3D graphics learning systems, learners can be immersed within any non-existing phenomenon visually, auditory, and haptically, thus helping them to comprehend the abstract data or concepts deeply and intuitively. For instance, variations in the intensity of sound may be used to indicate the current level of radiation, and different places could be given different colors that correspond to the current temperature in that area.

3D graphics learning systems enhance the learning by making the learning experience game-like, while still retaining the underlying content. 3D graphics learning environments are engaging, entertaining, attractive, interactive, and flexible. Because of their experiences with videogames, many students are highly motivated to play interactive, visually rich games. Students are better able to master and retain knowledge when they are actively

involved in constructing the knowledge through learning-by-doing.[7]

3D graphics learning systems allow us to create better learning environments for those students who have difficulty learning from the traditional classroom instruction. First, the bottom-third of students struggles with the abstract nature of physics. Second, some students are tired of the traditional classroom-style learning. They often give up on themselves as learners. These students are disengaged from classrooms and typically hard to motivate even by good teachers using inquire-based pedagogy. 3D graphics learning systems with intuitive content and activities that resemble the entertainment and communication media that these students use outside of school can reengage them in learning.

Finally, 3D graphics learning systems allow students to have learning experiences that are not possible within physical educational settings. At one extreme, the learner could interact with and even step into atoms and electrons, while at the other extreme acquire a sense of distance in the universe by visualizing planets and moons. 3D graphics systems provide us the ability to create any *imaginable* worlds that are not available in the real physical world.

In summary, 3D graphics learning systems are able to provide an intriguing potential complement to the traditional education system. In the following, we presented several 3D graphics learning systems we developed and experimented for teaching and learning purposes in the classrooms at Prairie View A&M University.

Learning Case 1: Newton's Laws of Motion

Newton's Laws of Motion consists of three laws that govern the relationship among mass, force, velocity, acceleration, distance, and time (six factors).

- 1st Law of Motion: Objects at rest or in uniform motion will stay in that state unless acted upon by a force.
- 2nd Law of Motion: Acceleration caused by a force is proportional to force and inversely proportional to mass.
- 3rd Law of Motion: Every action has equal and opposite reaction.

We developed three animation systems to provide an integrated environment for exploration of Newton's Laws of Motion as well as the conservation of both kinetic energy and linear momentum.

1) Learning Gravity Principle: Bouncing Ball in 3D Space

This system is intended for exploring *gravity* force governed by Newton's Laws of Motion, which is expressed as follows:

$$v_1 = v_0 + g \times \Delta t$$

$$h_1 = h_0 + v_1 \times \Delta t$$

Here g is the free fall acceleration of gravity (which is a constant) and h is the height of the object. Students interact with the Bouncing Ball Environment through the control panel floating at the bottom of the window. Within the Control Panel, there are three buttons for changing camera position and direction: (1) camera is attached to the ball and aiming at floor; (2) camera is installed on the floor and directed straight up; and (3) camera is located at height of human eyes and looks horizontally from certain distance away from the ball's vertical movement path, as shown in Figure 1.

Using the slide bars in the control panel, students can also change the mass and height of the ball, and add or remove air damping force, which is proportional and opposite to the velocity. Learners can catch and release the ball. The ball moves downwards, rebounding when it collides with the floor. In this system, students

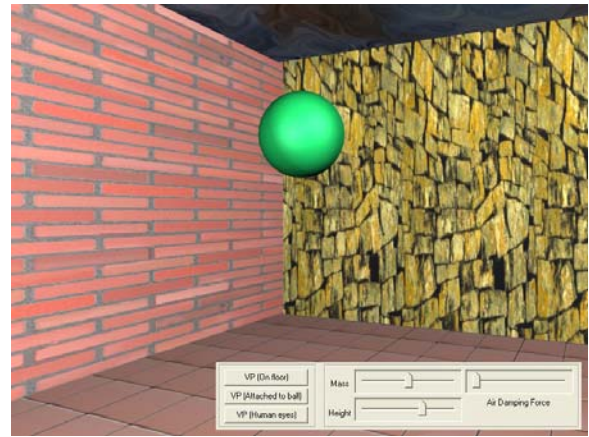


Figure 1: Bouncing ball animation for learning gravity principle.

will observe that changing object's mass does not affect the free fall velocity and acceleration of gravity.

To guide the learning process, we provide scaffolding that enables learners to advance from basic to more advanced activities. Students begin their guided inquiry in a world without gravity and air damping force, allowing them to perceive physics phenomena that are otherwise obscured by these forces. Then they can enable the gravity to experience the free fall movement. Finally, students can add air-damping force to the environment to explore the ball movement happening in the real nature world. They can use mouse to catch and free the ball and observe the collisions and bouncing. These activities provide an immersive experience of often counter-intuitive phenomena. By instructing students to make predictions about upcoming events, directly experience them, and then explain what they experienced, we encourage learners to question their intuitions and refine their mental models.

To aid students in judging the relationship among the velocity, acceleration, and distance, auditory and visual cues are integrated into the system. This helps students experience phenomena and direct their attention to important factors such as mass, velocity, and energy.

2) Learning Hooke's Law: Spring Animation

Hooke's Law says that the restoring force due to a spring is proportional to the length that the spring is stretched, and acts in the opposite direction. Hooke's Law is written as:

$$f_s = k(l_0 - l_1)$$

Here, f is the force acting on the spring, and $l_0 - l_1$ is the length the spring is stretched. k is a constant coefficient representing the physical property of the spring.

We created a Spring Animation to help students comprehend Hooke's Law. In the system, six balls are chained with seven spring segments. The two ends of the chain are tied to two pegs planting into the ground, as shown in Figure 3a. Each ball has four forces acting on it: the two forces from the left and right spring (f_{ls} and f_{rs}), the gravity of the ball (f_g), and the air damping force ($f_a = -\varepsilon \times v$), which is opposite to the ball velocity (v). This is shown in Figure 2. The sum of the force force, F , decides the acceleration of the ball movement.

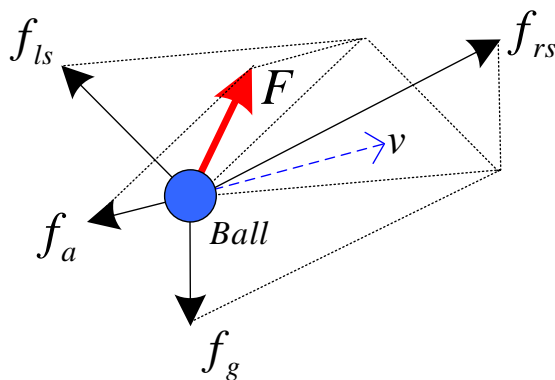


Figure 2: Forces acting on a ball.

The balls' movement is governed by the Newton's Law of Motion. Due to the effect of the air damping force that is proportional to the velocity of balls, the balls will all be at rest when all the forces are balanced.

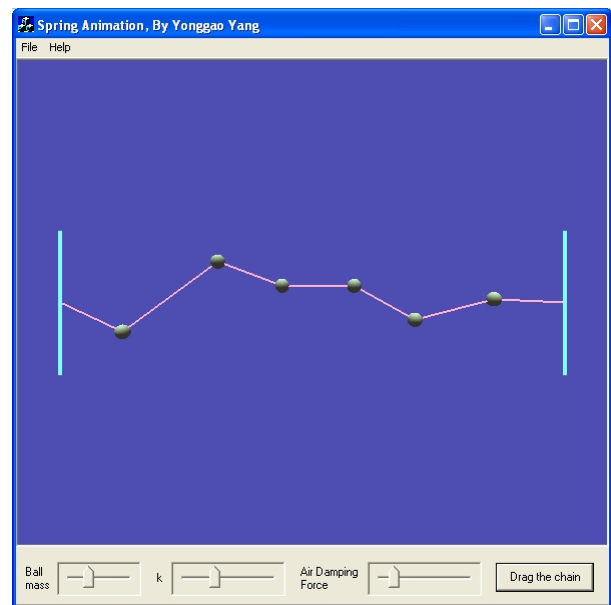
$$F = f_{ls} + f_{rs} + f_g + f_a$$

$$F = ma$$

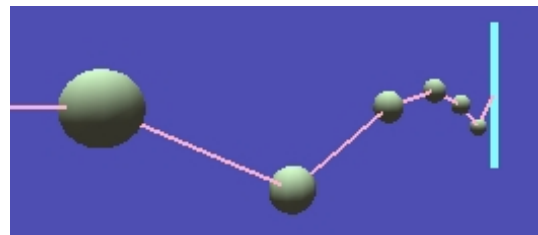
$$v_1 = v_0 + a\Delta t$$

$$d_1 = d_0 + v_1\Delta t$$

Students can manipulate three parameters to observe the behavior of springs governed by Hooke's Law: mass of balls m , spring coefficient k , and the air damping force coefficient ε . Students can also move mouse to change viewpoint freely in order to have close observation of the movement of balls and spring segments (Figure 3b).



(a) Spring animation based on Hooke's Law.



(b) Observe the animation from another angle.

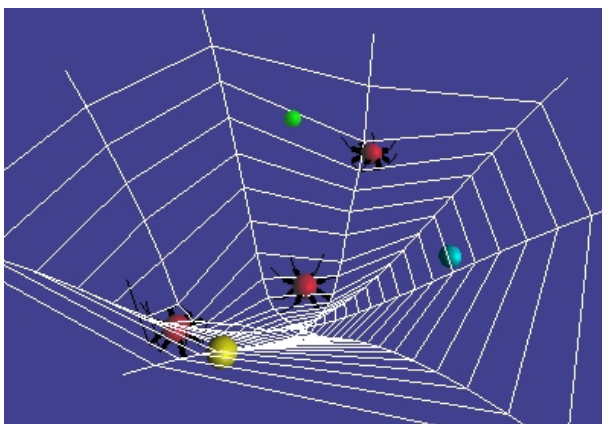
Figure 3: Use spring animation to learn Hooke's Law.

3) Learning Newton's Laws of Motion: Spider Web Animation

After experiencing learning from the above two 3D graphics learning systems, now students can comprehensively learn Newton's Laws of Motion from practicing this animation. We developed this comprehensive game-like animation: simulating spiders walking on a web in real time, as shown in Figure 4a. Again, springs are used to construct the simulation model. The details of the implementation can be found in our published paper.[3]



(a) Three spiders try to catch bugs on the web.



(b) Look at the web from another angle.

Figure 4: Spider web animation.

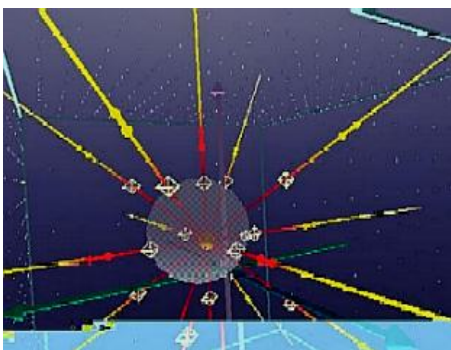
The animation of the spider movement and the web behavior is based on the Hooke's Law and Newton's Laws of Motion. Before allowing students to run the animation, instructors should give a brief introduction on how the system is implemented and how the physical laws are used to govern the animation. The system allows students to freely rotate the spider web along x-, y-, and z-axis (Figure 4b). The three balls representing the three bugs that the three spiders try to catch can be moved around in order to move the spiders on the web.

Learning Case 2: Virtual Maxwell World

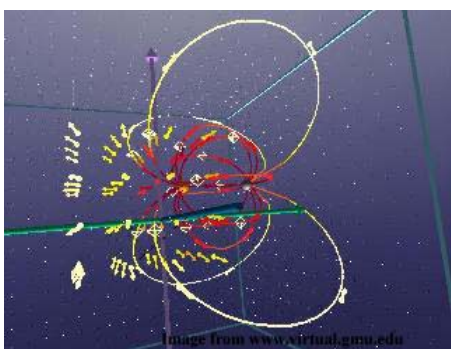
The Virtual Maxwell World was a research project directed by Chris Dede[5] at George Mason University. We were involved in maintaining the system. This system has been designed to enable the examination of the nature of electrostatic forces and fields, to aid students in understanding the concept of electric flux, and to help them empirically discover Gauss's Law. Maxwell World occupies a cube approximately one meter on a side with Cartesian axes displayed for convenient reference. The small size of the world produces large parallax when viewed from nearby, making its three-dimensional nature quite apparent. Menus and the 3-Ball are used for interaction in this world.

By controlling the camera, learners are allowed to walk-in to the virtual world, and place both positive and negative charges of various relative magnitudes into the world. Once a charge configuration is established, the force on a positive test charge, electric field lines, potentials, surfaces of equipotential, and lines of electric flux through surfaces can all be instantiated, easily observed, and controlled interactively. See Figure 5. For example, the tip of the index finger (representing the mouse icon) can be attached to a small, positive test charge, and a force vector associated with the charge depicts both the magnitude and direction of the force of the test charge (and, hence, the electric field) at any point in the workspace. A series of test charges can be dropped and used to

visualize the nature of the electric field throughout a region.



(a) An electric field in Maxwell World.



(b) 3D dipole: test charge traces and field lines.

Figure 5: 3D Virtual Maxwell World.

In a like manner, an electric field line can be attached to one of the charges and to the index finger (mouse icon). A student can then move his or her finger to any point in the workspace and see the field line that connects that point to one of the charges. Maxwell World can also display many electric field lines to give students a view of the field produced by a charge configuration. In another mode of operation, the tip of the index finger becomes an electric potential meter that, through a simple color map and a "=" or "-" sign on the finger tip, allows students to explore the distribution of potential in the world. Actual values of the potential can be acquired by interrogating a point; digitized speech then provides an audible numerical value.

Via the production of a Gaussian surface, the flux of the electric field through that surface can be visually measured. Spherical surfaces (Gaussian or equipotential) can be formed anywhere in the workspace by using the index finger to anchor the center of the sphere and then define the initial radius of the sphere. Upon activation, the surface grows from the selected radius terminus until a closed surface is formed. In the case of equipotential surfaces, the electric forces at any point on the surface can be shown as a color mapped onto the surface at that point. A point on the surface can be "grabbed" to expand or shrink the surface's radius, and its anchor can be moved at will. During all of these activities, the underlying physical simulation updates all physical parameters (force, field lines, and potential).

This 3D graphics learning system allows students to walk in the micro-, invisible world, to hear, feel, touch, and visually exam the nature of electrostatic forces and fields, to aid students in understanding the concept of electric flux.

Conclusion and Future Work

This article discusses using 3D graphics learning systems to enhance students understanding complex and non-intuitive science concepts and physics laws. The systems we developed can be merged and integrated as a complement tool to the traditional classroom teaching. All the systems are designed to run on regular desktop computers running Windows operating system.

Through such studies, we hope to share with and provide guidance to other developers and researchers who work on or interested in computer-supported learning environments. We hope our experiences contribute to not only students' learning, but also such systems' design and implementation.

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