2D and 3D virtual interactive laboratories of physics on Unity platform

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Abstract. Using the cross-platform game engine Unity, we develop virtual laboratories for PC, consoles, mobile devices and website as an innovative tool to study physics. There is extensive uptake of ICT in the teaching of science and its impact on the learning, and considering the limited availability of laboratories for physics teaching and the difficulties this causes in the learning of school students, we design the virtual laboratories to enhance student’s knowledge of concepts in physics. To achieve this goal, we use Unity due to provide support bump mapping, reflection mapping, parallax mapping, dynamics shadows using shadows maps, full-screen post-processing effects and render-to-texture. Unity can use the best variant for the current video hardware and, if none are compatible, to use an alternative shader that may sacrifice features for performance. The control over delivery to mobile devices, web browsers, consoles and desktops is the main reason Unity is the best option among the same kind cross-platform. Supported platforms include Android, Apple TV, Linux, iOS, Nintendo 3DS line, macOS, PlayStation 4, Windows Phone 8, Wii but also an asset server and Nvidia’s PhysX physics engine which is the most relevant tool on Unity for our PhysLab.

1. Introduction
This paper focuses on the development of innovative tool in which the learners could interact with movable virtual laboratories based on the platform Unity that include virtual apparatus and materials and conduct experiments on a movable device as well as on a computer. The knowledge of new Information and Communication Technologies (ICTs) is directing traditional learning environments, especially in theoretical-practical courses, towards new learning environments, which can articulate the direct teaching line, as suggested by Larreamendy-Joerns and Leinhardt (2006) [1]. Those virtual laboratories become a popular alternative because they are more flexible, safe, manageable, clean, cost-efficient and fast than physical experiments [2, 3]. These new innovative and interactive learning scenarios not only allow us to form more competitive citizens within a society that revolves around information and software tools, such as computers, tablets and smart phones, that facilitate communication processes, but also they are advancing at their own pace [4–8]. Several studies have shown the amazing learning effects of virtual environments that support students to test hypotheses, explore and analyze data as experts do [9–11]. Studies conducted by the US Department of Education (2009) show that online instruction, in general, may be more beneficial than the traditional one and shown the advantages of virtual laboratories in concept learning [2, 3, 12]. Given the impact of this new learning environment and the limited availability of laboratories for teaching physics in the institutions...
of secondary education, the authors developed a series of virtual laboratories with the objective of supporting the work of teachers and the improvement of Compression of students about fundamental concepts of physical phenomena [13–16]. As a result, there is an increasing number of researchers that propose the replacement of physical laboratories by virtual ones. Our virtual laboratories include a guide for each of the experiments, which contributes to reduce the cognitive load and, therefore, facilitate meaningful learning as it was studied [17]. The guide can also be used to prevent random interactions with simulations and to focus on important parameters and concepts. As a result, virtual laboratories can effectively improve student learning concepts. To develop the virtual laboratories on Unity platform we decided to use the video game drive unit, since it is a platform that can be used for developments in Windows, Linux, Android, Apple and for video game consoles, stories such as Xbox-one, Play Station among others and mobile devices. The graphics drive engine uses the OpenGL libraries, for Microsoft Windows, Mac and Linux; Direct3D, for Windows and OpenGL ES, for Android and IOS. In addition to this it supports relief, reflection and parallel mapping, dynamic shadows and rendering of textures that facilitate the design and creation of virtual scenarios in 2D and 3D. Its integrated physics engine provides a set of components that are very useful for the simulation of physical phenomena [18].

The studies through educational website, videoconferencing and different educational platform are not significantly different from regular classroom learning in terms of effectiveness. In light of today’s learning applications, which can take advantage of a wide range of the resources, including not only Web-based and multimedia but also using tools as Unity which open the opportunity to develop apps that can improve the way to catch the attention of new generations of young people who grows in a technological world. Our apps are develop to obtain a better understanding of the study of physics in a enviroments that simulate a video game and which can offer a realistic view of the physical phenomenon considered in the virtual laboratories. According to Gordon and Pea (1995) the use of Scientific Visualization (SciVis) through virtual laboratories improves learning because it supports the thought process and the methods followed by the researchers [19]. In (2002) Fisher and Unwin argue that visual interfaces maximize perceptual skills and facilitate understanding of the characteristics of geographic ecosystems [20]. In addition, the simulation of physical phenomena offers students the opportunity to test their hypotheses about them, which in the real world is impossible and test multiple scenarios to get an idea of possible outcomes taking into account these assumptions, for instance, in 2002, Barak and Nater developed a virtual Virtual museum of minerals and molecules: Molecular visualization in a virtual hands-on museum [21].

2. Unity 3D and design of physical laboratories simulation

Unity 3D was developed by Unity Technologies in Denmark and is a game development ecosystem, a powerful rendering engine fully integrated with a complete set of intuitive tools and rapid workflows to create interactive 3D and 2D. One of the key features of Unity 3D is its support for modeling physical properties. For example, one can assemble objects, using a variety of joints. Also, various objects can have mass, compliance, collision detection, etc. One of the main differences from the realXtend platform is that Unity 3D comes from the FPS (First Person Shooting) game arena, whereas realXtend is a multiuser social collaboration environment. The platform of the Unity allows to create new materials through its inspector module in which dialog box of that module is illustrated (see Figure 1). Its rendering power enables a high fidelity of the objects created, which can be integrated into the virtual world or laboratory and its integrated physics engine provides a set of components that are very useful for simulating physical phenomena. For example, the Rigidbody component allows you to recreate object dynamics through the "Is Kinematic" property, changing its value from a script can activate or deactivate the physics of an object as shown in Figure 2 and in Table 1 we lists the functions of the properties of the Rigidbody component. Another of the components of this platform...
is the Colliders, it is used to determine the shape of the objects when they collide, that is, they simulate the physical properties of the material that supposedly represent. For example, a rubber ball should bounce when dropped. If you want to attach a RigidBody to another or to a fixed point you use the Joints tool, the Hinge Joint command causes the object to rotate around a specific point or axis. A very useful component is the Constant Force, when adding a constant force to a RigidBody, in Figure 3 shows the dialog box of this component. In Figure 4 shows a virtual scene created by this platform, which shows not only its rendering power, but also lighting effects, shadows among others.

Figure 1. Inspector module dialog box.  
Figure 2. RigidBody component properties dialog box.
3. Virtual laboratories

In this paper we present 3 of 22 virtual laboratories developed in an environment in which different devices can be selected to check different laws of physics (see http://simulacionfisica.unimagdalena.edu.co/) in which the area for data entry is modified to obtain results in output area (also see Table 2). We can see that the machines for performing the experiments of free fall, coefficient of friction and parabolic movement (see Figures 5, 6, 7 respectively) shown an environment that can attract the attention of the students easily. The virtual laboratories create a powerful versatile tool which is linked to a laboratory guide, which facilitates the learning of each physical phenomena. It is possible to find in this guide questions, tables for recording data to obtain representative graphs of the physical phenomenon, analysis of equations and conclusions area.

We propose a set of laboratories in which the students recognize relevants variables of the simulated phenomenon, the relation exists between them and the physical laws that explain the phenomenon. Each laboratory is accompanied by a structured guide as follows: Name of laboratory, standard, competences to be developed, problem question, curricular area, achievement to develop, indicators of performance, theoretical foundation, simulation, observation of the phenomenon, calculations, results and analysis. This structuring of the guides, evidences that the learning mechanisms to achieve the appropriation of the knowledge on the part of the students are: Learning based on observation, competence-based learning, learning based Scientific Visualization (SciVis) and learning based on abstraction.

Table 1. Rigidbody properties and functions.

| Property            | Function                                      |
|---------------------|-----------------------------------------------|
| Mass                | Mass of object                                |
| Drag                | Resistance to air                             |
| Angular Drag        | Related air resistance when rotating          |
| Use gravity         | Enables or disables gravitational acceleration |
| Is Kinematic        | Enables or disables the physics engine        |
| Interpolate         | Enables or disables interpolation             |
| Collision Detection | Enable or disable collisions                  |
| Constraints         | Restrictions on the movement of Rigidbody    |

Figure 3. Constant strength component dialog box.

Figure 4. Scenario created using Unity.
Figure 5. Parabolic movement: Combination of two movements (uniform rectilinear and free fall).

Figure 6. Free fall: Determination of the gravitational acceleration and its relation with the movement of the celestial bodies.

Figure 7. Coefficient of friction: Friction. Determination of the coefficients of static and kinetic friction.
Table 2. Virtual laboratories.

| Virtual laboratory                      | Description                                           |
|----------------------------------------|-------------------------------------------------------|
| Velocity and acceleration              | Relationship between the variables distance, time     |
| Simple harmonic movement               | Period and frequency in harmonic motion                |
| Simple pendulum                        | Analysis of period and length of the pendulum          |
| Torsion pendulum                       | Study of period, inertia and torsion coefficient       |
| Waves                                  | Kinematics of the wave motion                         |
| Collisions                             | Linear momentum and its conservation principle         |
| Newton’s second law                    | Concept of inertial mass. Force and acceleration       |
| Energy                                 | Concept of energy. Kinetic and potential energy        |
| Archimede’s principle                  | Pushing force. Relationship with weight and density    |
| Circuit design                         | Resistors and capacitors in series and parallel        |
| Kirchhoff Laws                         | Principle of charge and energy in electrical circuits  |
| Charging and discharge of a capacitor  | Loading and unloading a capacitor through a resistor   |
| Lenses 1 and Lenses 2                  | Notable rays. Formation of images                      |
| Snell’s Law                            | Concepts of angles of incidence and refraction         |
| Conducting wire                        | Study of resistivity. Relationship area and length     |
| Average and instantaneous acceleration  | Analysis of ratio of velocity and time                |
| Capacitance                            | Combination capacitors. Serie and parallel             |

4. Conclusions
The goal of this paper was to present a novel 2D and 3D dimensional virtual laboratories based on the cross-platform game Unity to open the range to access in the study of physical phenomena, due to the users can work properly every Web or by download our app in Google Play, App Store and Windows store. In the future our vision is to overcome the barriers that still prevent the wide scale implementation of the distance-learning, through the use of virtual physics experiences. The authors are aware that virtual lab systems and simulators are often used only as an initial step in a student’s engineering education and training, followed by more in-depth hands-on experience with real authentic equipment. Nevertheless, need to recognize, based on the current state of art, that the progress in Virtual reality, computer graphics, and world technologies can offer the chance to encrease rapidly the use of virtual laboratory based systems applications, and eventually reduces the need for real world laboratories altogether. Finally, the guides developed in this research are according to the implementation of immersed education and distance learning, due to important relationship between the field of pedagogy and the desing of effective learning.

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