Conceptual Learning of Science and 3D Simulations

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Abstract. *The paper explains various approaches to present natural phenomena and technical examples by means of simulations accompanied by 3D visualisation. The background of the article is the experience with development and deployment of highly interactive didactic material concerning technical science by means of most advanced information technologies. Particular attention is given to interactive simulations in physics, chemistry, electrical engineering and computer engineering. Such research is conducted within international CoLoS consortium and the achievements are verified in various educational environments. Such test-beds are also schools and some faculties in Slovenia. The learning population was represented by university students but also by secondary school teachers of informatics. The article is focused on the interactivity and realistic 3D visualisation of the natural and technical concepts, the integration of such topics in interactive tutorials, and the dissemination alternatives offered by the information technologies.*

Keywords. *Didactics, multimedia technologies, simulations, 3D visualisation*

Introduction

CoLoS (COnceptual Learning Of Science) is a consortium founded in 1988, composed of research teams from 18 universities. Fields of interest of various CoLoS research groups are: physics, chemistry, electrical engineering, mechanical engineering, and computer science. The major goal of this consortium is to encourage and co-ordinate the development of teaching methods and to improve the knowledge and understanding of fundamental concepts with a special focus on intuitive and qualitative approaches. One of the methods that has been developed by CoLoS is based on the mimicry of nature and its fundamental principles. The computer is used for the visualisation of the molecular or atomic behaviour. The teacher or students can interact with the simulated system and in such a way obtain a better understanding. From the technical point of view this is achieved through 2D or 3D visualisation of simulated world, equipped with the needed control buttons, sliders and other possible interacting components.

3D Simulation of particles and non-rigid bodies

One of the most significant CoLoS authoring tools is xyZET [1], which was developed at IPN Kiel (Germany). This is an interactive, graphically oriented simulation tool that permits the presentation of objects and structures in 3D space. The basic building elements of these objects are particles that are defined by their mass, charge, and initial position and velocities. These particles can be connected with springs. In such a way more complex, non-rigid bodies can be presented. Different internal and external forces influence the particles in the system. Their behaviour can be observed during the animation. The basic phenomena from the domain of mechanics and electricity can be explored (kinematics, conservation of energy and momentum, Hook's law, gravity, charges, field lines and equipotential planes).

The conceptual learning of the particular phenomena can be achieved by incremental building of the first simple and then increasingly more complex bodies and structures, and by experimentation with various physical parameters. The teaching scenario can be included in accompanying and interacting hypertext. In such a way complete courses in the domains of mechanics and electricity have been created.

The figure 1 displays a screenshot with the experiment comparing a mathematical and a physical pendulum. The 3D world with the experiment is visualized in a separate frame. Besides this the accompanying control frame and hypertext based tutorial is presented.

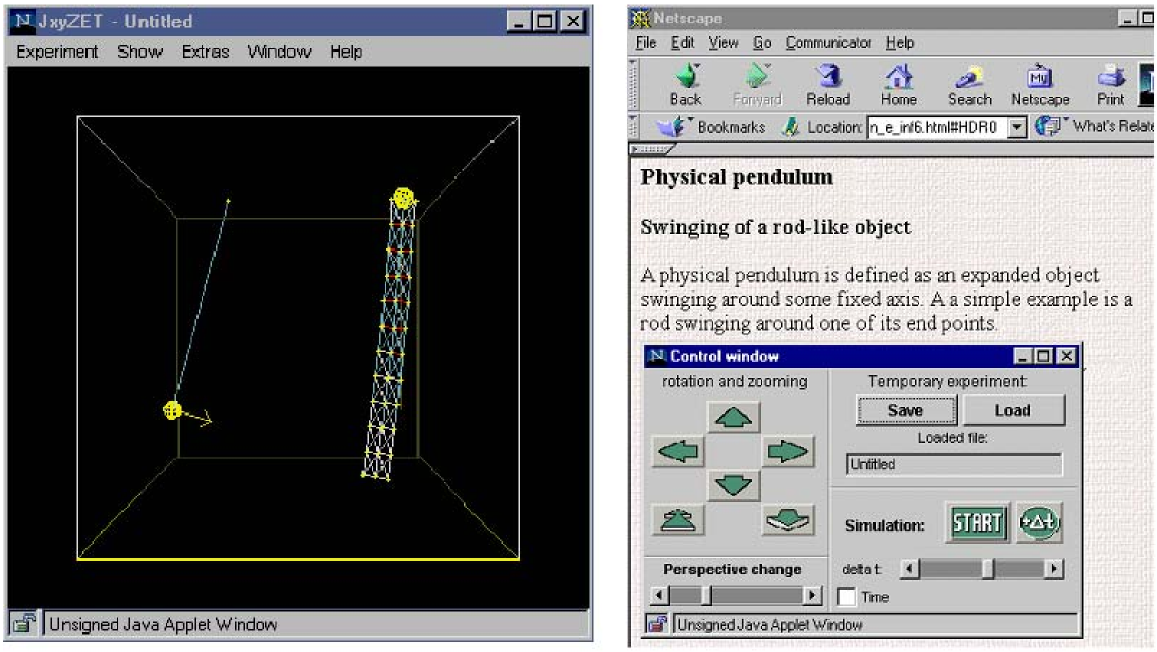

Figure 1: A screenshot with a mathematical and a pendulum

The gallery of several hundreds experiments includes some extremely complex examples with bodies consisting of more than 100 interconnected particles. Most of the experiments were integrated within the tutorials covering mechanics, resonance and electricity.

xyZET is an authoring tool running in MOTIF environment. Besides this, some additional platform independent java applets were developed at Ljubljana University. The final version was entitled JxyZET. The user interaction with experiments is achieved through buttons, menus, sliders and checkboxes that are I ntegrated in the tutorial. Several tutorials in the domain of physics, mostly written by H. Haertel and some by CoLoS group from Murcia (electricity, resonance), were adapted.

Flexibility of JavaScript Controlled Simulations

The next chapter presents the advantages of using JavaScript functions in interaction with scriptable applets. Very good results were obtained by the so called Physlets, which were invented by Wolfgang Christian [3]. Physlets - Physics Applets, are small flexible Java applets designed for science education. They can be used in a wide variety of WWW applications. The graphics of physlets is simple and without details that could be more distracting than helpful. This keeps Physlets relatively small and very flexible. All Physlets can be set up and controlled with JavaScript, which means that they can be used for several application problems with small changes in the JavaScript. Data gathering and data analysis can be added when needed, through the use of inter-applet communication. Since Physlets are scriptable, the experiments can be modified just by editing the HTML.

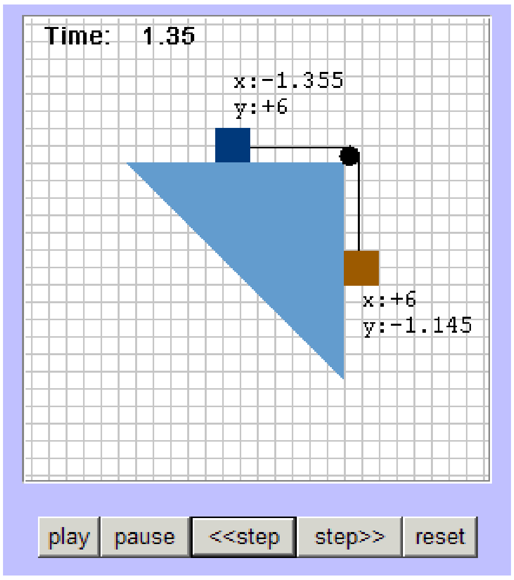

Figure 2: Physlet presenting 2 connected bodies

Christian's concept of scriptable applets influenced further development of JxyZET simulation applet. The original JxyZET was expanded with some scriptable functions. This permits the definition of more complex elastic bodies built from several hundreds or even thousands of particles and springs. These bodies can be easily modified just by changing some parameters within the JavaScript code included in the parent hypertext. The usage of JavaScript permits the interaction of an user defined algorithm with the simulation tool, in our case JxyZET. Further research of JavaScript capabilities permitted some additional improvements and increased flexibility of this simulation tool, which was completely redesigned and renamed in Animator3D.

The achieved flexibility of Animator3D applet permits the development of experiments in different scientific domains because we can put the simulation algorithms in externally defined JavaScript and are not limited with the algorithms incorporated in the original applet. The following example is a simplified 3D simulation of the known nuclear fission process.

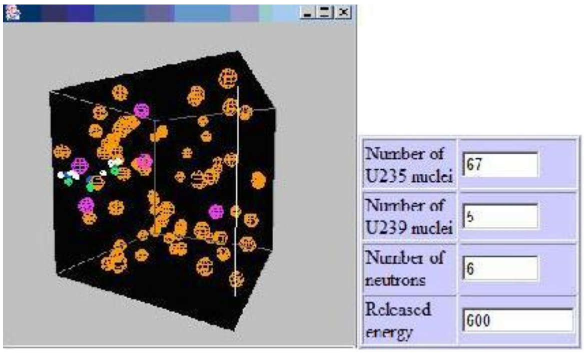

Figure 3: Simulation of a nuclear fission process.

The experiment consists of putting a quantity of U235 nuclei, some U239 nuclei and one neutron with a predefined velocity in a container. Every time a neutron collides into a U235 nucleus the later is split in two smaller nuclei (waste product) and two additional neutrons are created. In addition some new energy is released. U239 acts as an absorber. Every time a neutron collides into a U239 nucleus it is absorbed by the later. The experiment aims to find a balanced number of U235 and U239 nuclei so that the chain reaction neither dies because of disappearance of all neutrons nor it becomes too rapid (as in uncontrolled fission).

4. Photorealistic visualisation in 3D

One of the problems of such simulations is that the students have sometimes problems with understanding abstract visualisations even if they are presented in 3D space. The problem is how to decrease the gap between the real world which surrounds us and the abstract models which are used in simulations. One of the possible solutions could be to use a more realistic visualisation and to approach the abstract presentation stepwise. The interactive programs can be even more attractive if written in some more realistic 3D visualisation environment. There are several WEB technologies, which permit such visualisation. Considering the needs of interactivity, the focus of the research was oriented in Java3D.

The interactivity of the hypertext user with these demo programs can be easily achieved by means of JavaScript routines that interact with public functions within applets. The problem of such demonstrations is that the client computer should have installed corresponding Java runtime environment (for java3D) and therefore such courseware is less platform independent as is the case with usual interactive applets. Such approach is therefore more appropriate for classroom demonstrations during lectures.

The next figures presents the possibilities of such visualisation and shows a complex 3D model of a steam engine.

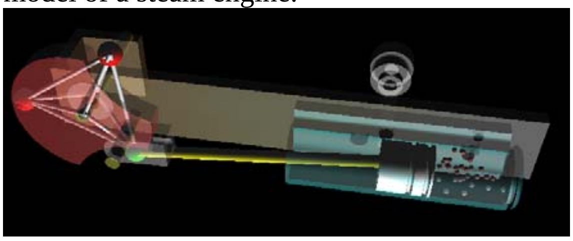
Figure 4. A 3D model of a steam engine

The transparency of the parts of this complex 3D model can be changed as shown in the figure. The figure shows the superposition of this 3D model with its abstract physical equivalent. In the cylinder a container with monoatomic gas is introduced. The length of the container (its volume) changes due to the pressure of this gas. The position of the piston in the cylinder depends on the volume of the container. The inertia wheel is substituted by several particles interconnected with springs. One of the particles of the wheel is connected with another spring to the piston.

Another interesting approach was used in the simulation of the already mentioned nuclear fission reactor. This simulation can be made more impressive by means of the following approach: The model of the nuclear fission reactor is represented by a 3 dimensional container which includes a quantity of U235 nuclei and one neutron with a predefined velocity. Besides this it includes two moderator rods (containers with some U239 nuclei), which can be moved up and down, thus controlling the reaction.

In order to give a more realistic view the background of the experiment is presented with a textured plane along with a picture of the reactor, scanned from a textbook. By changing the transparency of this picture we can gradually move from the realistic to the more abstract view.

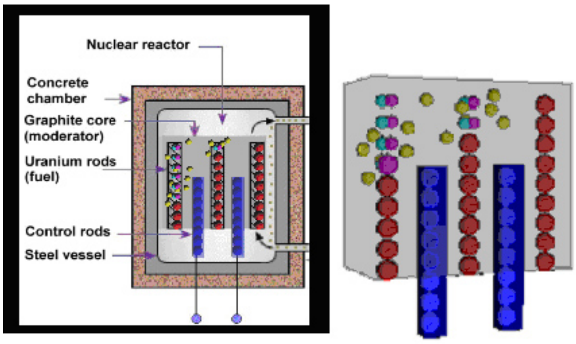

Figure 15: Example with nuclear fission reactor

The same technology can be used for a realistic presentation of the simulated physical phenomena and permits also education through play and fun. In fact such experiments resemble the well known computer games. The next figure shows such simulation of two colliding 3D bodies. The cars on the picture are in fact 3D models with corresponding masses and velocities. A student can study the fundamental rule of energy conservation by changing the physical properties of the visualised objects.

Figure 18: Realistic visualisation of the collision between bodies

The presented visualisation technologies are not limited to teach physics and the same approach was tested in other domains, in particular chemistry, biology and even computer graphics and computer programming.

6. Conclusions

The interactivity of the hypertext user with Java based demo programs can be easily achieved by means of JavaScript routines that interact with public functions within applets. The problem of such demonstrations is that the client computer should install the corresponding Java runtime environment. When more advanced 3D examples (for java3D) are implemented such courseware is not platform independent, as is the case with usual interactive applets. Such approach is therefore more appropriate for classroom demonstrations during lectures.

References

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