Multimedia Interactive Simulations
of Physical Experiments

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Abstrakt. Most of the multimedia CD ROMs offer static or unchangeable items like texts, images, sounds or videos without any user interaction. We have created an interactive CD ROM, which simulates several elementary experiments in physics. The CD ROM can be used as a learning tool in the educational process. Before entering this virtual laboratory, students are offered a brief introduction to the simulated problems. Our software has been developed using Macromedia Flash MX, which offers the opportunity to control the running application by changing several parameters. After setting the parameters a physical experiment is simulated and shown to the student via animation.

Key words: multimedia application, virtual laboratory, interactivity, simulation, animation.

1 Introduction

This work was motivated by the book "Physics as an Adventure of Cognition" [2]. The authors state questions and give answers on many processes in physics. In explanations they do not use any formulas or equations. They exploit imagination, experiences and common sense. The book is addressed to all age categories.

However, children may find it difficult to fully understand the processes in physics. They do not have enough experience and can not imagine physical processes in a very complex view. Therefore we decided to create an application on CD, which will illustrate the physical experiments in progress. Children can learn the processes by playing with animations. Since we wanted to give children realistic experience we attempted to create as realistic animations as possible. This goal required interactive applications containing animations, sound and text. The best solution was to create an interactive multimedia application.

Our motto is: "Experience is the best teacher." Intuitive interactions are the most important parts of our application. However, it is impossible to let users interact in whatever way they want. So we pre-tested our animations and asked users which parameters they would like to change and how. Then we adjusted our application accordingly.

2   Related approaches

There are many non-interactive animations. Hundreds of them are physical experiments and some of these experiments are a little interactive, but they are mostly autotelic. One very interesting webpage [3] offers a wide range (approximately 50) of physical experiments from different fields of physics. Simulations are programmed in Java. Animations are only schematic. There are only a few parameters which can be changed in each of them. If a user is not familiar with physical simulations, he may not understand what is going on. The web pages do not offer any explanations for the shown simulations.

In our market, we found only one CD-ROM that contains physics [4]. The application on this CD-ROM is in the Czech language; therefore Slovak children mostly do not understand it. This product was created to practice the calculations of physical formulas and it is intended for pupils in the second grade of elementary school (10 to 14 years old). It contains 21 types of tasks from mechanics, heat energy and optics to electricity, which is quite a wide range. Each task contains a schematic animation, which a user should play first; a calculator and some constants are supported if necessary. During the animation, relevant numbers of physical quantities are shown. When the animation ends, the user is asked to calculate one missing physical quantity. Then the user can check his answer. The animation control is not intuitive and we did not find any help there.

Of the CD-ROMs we found, the only interesting one was a CD-ROM containing physics [1], but it explained the curriculum like teachers do in school. The application on this CD-ROM is a simulator, which lets teachers and students model experiments on-screen. The animations are only schematic. The user can use a wide range of components to set up the simulations. The experiments are in areas of electricity, optics, oscillations, force and motion and waves. Students can interact quickly and simply by dragging components from the toolbars and the results can be plotted.

3   Simulated physical processes

Our project offers users interactive virtual physical laboratories. They can "play" with animated simulations and influence the processes in motion. We created four realistic experiments – Cart on Inclined Road, Pendulum on the Rod or the String, Space and Shooting Cannon. There are various parameters which the user can change. The basic parameters are changeable intuitively like attributes of the objects located in the scene. Via interactions the user can understand the processes with little explanation. There are a minimum of words and no formulas.

3.1 Scenario

For better imagination we divided all scenes of a scenario into levels as follows:

- **Level 0** is when the application starts running. The first action is that the introduction starts playing. This ends on the page with the content and the settings. In the content the user can choose one of the offered laboratories.
- **Level 1** starts with entering one of the laboratories. Each laboratory starts with playing the part named "Questions" and continues to the part named "Interaction" and finally ends with the part "Experiment." From the part "Interaction" the user can see and hear the instructions on how to interact with the objects.
- **Level 2** offers interaction in an experiment. The user can use either the mouse or keyboard. He can click on the button "START!"/"STOP!" (or to press Enter/Space) or to choose one of five menu buttons: "show numbers"/"hide numbers," "change numbers," "questions," "interaction" and "content." Finally, the user can also change the attributes of the changeable object.
- **Level 3** are faders in the special menu, which appears after the clicking on "change numbers" button.

The buttons and the changeable objects in level 2 and level 3 change their color whenever the mouse pointer is moving over them to attract the user for interaction. The user can interact with the objects by changing their position, scale or rotation. As a consequence of this he is changing the values of the parameters. The menu with five buttons appears if the user moves the mouse pointer to the top of the screen.

3.2 Free parameters

We let the user change the values of some parameters. They are usually those which can show something interesting and therefore are important for understanding the physical process. These parameters can be changed in two ways. One way is to change the attributes of interactive objects by mouse and the second way is to use faders in a special menu. To find out the appropriate number of the free parameters we did pre-testings. They showed that approximately five parameters changeable by mouse and ten parameters changeable by using the special menu are enough. For some types of objects it is necessary to use a combination of the mouse and a key. In the special menu there are two groups of parameters. The first group contains the parameters that are changeable in the first way. The second group contains parameters that are interesting but not so important for the basic understanding of the animation. The second group gives the user a "higher level" of control. We assume that the users will use the second group only if they fully understand what these parameters mean.

3.3 Animations of physical experiments

1.1.1 Pendulum on the Rod or the String

This model combines two other simple models. The first one is a mathematical pendulum with a deviation from the equilibrium point caused by an initial amplitude or velocity and consequently oscillating due to a gravitational field. The second one is a body hung on a string oscillating harmonically due to an initial deviation from the

equilibrium point and an elastic force proportional to the negative instantaneous deviation. By the appropriate choice of the parameters one can obtain oscillating modes corresponding to the first, second or the combined model. The model does not have the constraint for the pendulum deviation as the simplest theoretical relation for the period of mathematical pendulum.
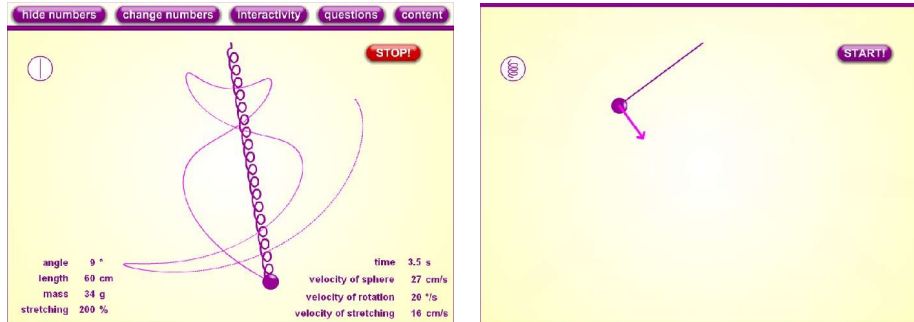
Figure 1: "Pendulum on the Rod or the String" screenshots.

By dragging the hung ball the position of the ball and therefore, the angle and stretching of the spring (resp. length of rod) are changed. After pressing "v" a pink arrow starting in the middle of the ball appears. This arrow represents velocity. After pressing "m" the ball is scaleable. The size of the ball represents the mass of the ball. If the mouse pointer is close enough to the relevant object, the arrow of velocity or the size of the ball can be changed. Their size is proportional to the distance between the mouse pointer and the center of the ball.

The ranges of the parameters are shown in Table 1 and their different settings are in Figure 1. The following basic parameters with other relevant quantities can be found in the "Numbers" section at the bottom of the application window: time, angle, mass, length, stretching, velocity of sphere, velocity of stretching and velocity of rotation.

Table 1: Free parameters, their ranges and control keys for "Pendulum"

changing place		in animation		in special menu		keys
	parameter	range		range		
	mass of the body	1 g	150 g	1 g	200 g	m + arrows
position of the body	angle	as possible		-90°	90°	arrows
	stretching	10 %	150 %	10 %	200 %	
speed of the ball	angular	0 m/s	1 m/s	-180°/s	180°/s	v + arrows
	radial			-0.5 m/s	0.5 m/s	
equilibrium length of the string		10 cm	40 cm	5 cm	50 cm	l + arrows
gravitational acceleration		-	-	3 m/s^2	12 m/s^2	-
force constant of the string		-	-	1	10	-
time step		-	-	0.001 s	1 s	-
rod or string		button		-	-	r / s

1.1.2 Cart on Inclined Road

This model was chosen to demonstrate one of the often seen phenomena - the motion of a body on the road with a friction force between the road and wheels caused by the

internal source of torque and eventually a parallel component of gravitational force when the road is inclined.

By dragging the left end or the right end of the road the inclination of the road is changed. This is achieved by rotating the road around its center. A small turning arrow appears when the mouse points in the right place for dragging the road. By dragging the small circle on the load of the cart the user changes the size of the load. This is achieved by moving the top Bezier point of the curve representing the border of the load. By dragging the cart to the right or left the position of the cart is changed. The cart can not be placed out of the road. By dragging the rough orange line the coefficient of friction is changed. This is achieved by scaling the line with the scale-center in the center of line.
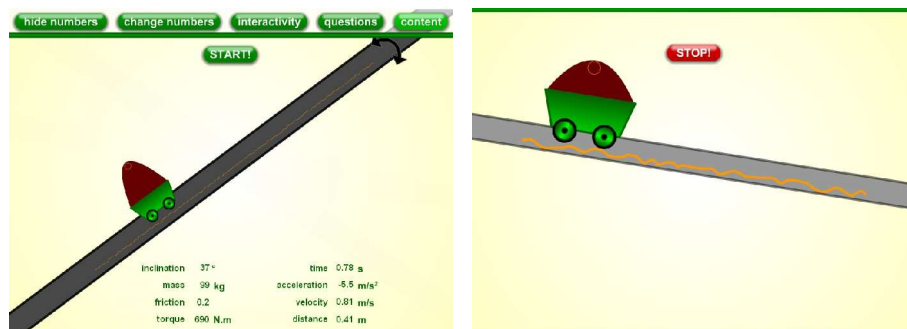

Figure 2: "Cart on Inclined Road" screenshots.

The ranges of the parameters are shown in Table 2 and their different settings are in Figure 2. The following basic parameters with other relevant quantities are placed in the "Numbers" at the bottom of the application window: angle, mass, friction coefficient, torque, time, acceleration, velocity and distance.

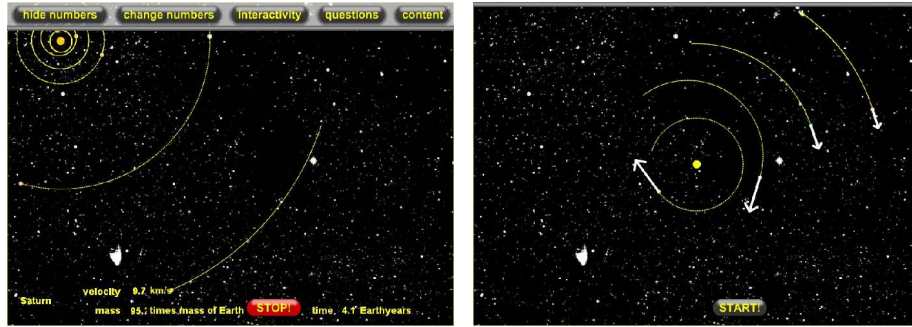**Table 2**: Free parameters, their ranges and control keys for "Cart on Inclined Road"

changing place	in animation		in special menu		keys
parameter	range		range		
angle of road inclination	-46°	46°	-60°	60°	a + arrows
friction coefficient	0.2	1	0	1	f + arrows
mass of the whole carriage	40 kg	100 kg	30 kg	150 kg	m + arrows
position of the cart	as possible		-	-	arrows
initial velocity	-	-	-5 m/s	5 m/s	-
gravitational acceleration	-	-	3 m/s^2	12 m/s^2	-
internal torque	-	-	-500 Nm	500 Nm	-
time step	-	-	0.001 s	1 s	-
length of 1m	-	-	30 pixels	260 pixels	-
brake	on	off	-	-	b

1.1.3   Space

This model represents a simulation of the N-bodies problem which are mutually attracted by the Newton gravitational force. The force is proportional to the masses of the objects and reciprocal to the square of the distances. In the beginning each body is

given its initial conditions as x and y spatial and velocity coordinates. Then the model evolves with the time scale much faster than in real situations to achieve a reasonable performance for observing the character of the motion of the bodies.

Figure 3: "Space" screenshots.

By dragging the spatial bodies their position is changed. After pressing "v" the white arrows starting in the center of the bodies appear. These arrows represent velocities and by dragging them their angle and size can be changed.

Table 3: Free parameters, their ranges and control keys for "Space"

changing place		in animation		in special menu		keys
	parameter	range		range		
body selection		selected by mouse		chosen from the list of bodies		tab
position of the body		as possible		-	-	arrows
velocity	tangential	0 km/s	100 km/s	0 km/s	200 km/s	v + arrows
	radial			0 km/s	200 km/s	
weight of the body		-	-	10^{20} kg	10^{32} kg	-
length of 1AU		-	-	5 pixels	260 pixels	-
time step		-	-	1000 s	1000000 s	-

The ranges of the parameters are shown in Table 3 and their different settings are in Figure 3. The following basic parameters with other relevant quantities can be found in the section "Numbers" at the bottom of the application window: weight and velocity of the nearest spatial body to the mouse pointer, time.

1.1.4 Shooting Cannon

Another simple physical model is a model of a shooting cannon. It describes a moving object in the presence of a homogenous gravitational field, a dragging force caused by an environment of a specific density and its own velocity. The initial conditions of the body are the distance from the ground, the speed and the angle between the cannon and the ground surface.

By dragging the cannon, the angle of the shooting is changed. After pressing "v" a black arrow starting in the middle of the spherical stone appears. This arrow represents the initial velocity of the object. If the mouse pointer is close enough to the arrow, the velocity can be modified. The velocity is proportional to the distance between the mouse pointer and the center of the stone. After pressing "m" the number on the stone is changeable. This number represents the mass of the stone.
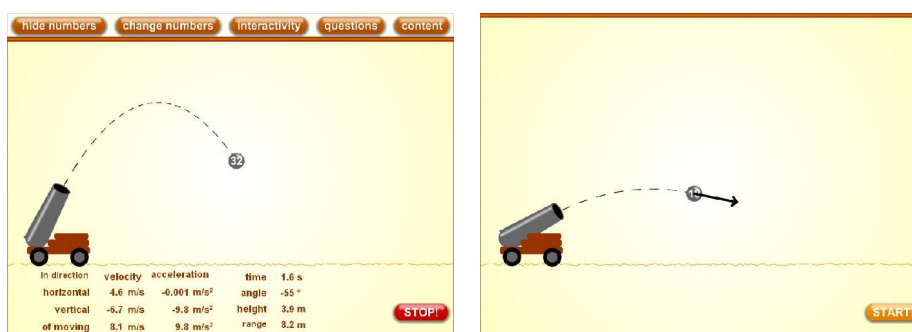

Figure 4: "Shooting Cannon" screenshots

The ranges of the parameters are shown in Table 4 and their different settings are in Figure 4. The following basic parameters with other relevant quantities are located in the section "Numbers" at the bottom of the application window: time, angle, height, range, velocities and accelerations – horizontal, vertical and both together.

Table 4: Free parameters, their ranges and control keys for "Shooting Cannon"

changing place	in animation		in special menu		keys
parameter	range		range		
mass of the body	1 kg	20 kg	0.1 kg	50 kg	m + arrows
position of the body	as possible		-	-	arrows
velocity — size	1 m/s	100 m/s	0.1 m/s	150 m/s	v + arrows
velocity — angle	-90°	90°	-180°	180°	a + arrows
density of environment	-	-	0 kg/m^3	1000 kg/m^3	-
velocity of environment	-	-	-100 m/s	100 m/s	-
gravitational acceleration	-	-	3 m/s^2	12 m/s^2	-
length of 10 m	-	-	30 pixels	260 pixels	-
time step	-	-	0.001 s	1s	-

3.4 Implementation

To implement the experiments we choose Macromedia Flash because it allows creating multimedia applications and it has its own program language – ActionScript.

It allowed us to create interactive animations. This language is an object-oriented language which gives many advantages. Pictures created in this software are vector graphics, they need a minimum size of operating memory and also minimize computational complexity. Next, it is possible to import raster images. To create non-interactive moving vector graphics we used pre-programmed motion or shape tweening. Some types of objects are pre-programmed. The basic objects are a layer in timeline, a movie clip, a button, a graphic object and a component. The movie clip and the button need to interact first with the mouse or the keyboard and then one can run certain parts of the program. This software also allows importing sound and video.

4   Future work

There are other areas of physics and science in general that can be brought to children via interactive animations. To make our application more attractive we can add some background music, real videos and photographs. This application can be implemented on the INTERNET too.

5   Conclusion

We have tested our application with five groups, each with approximately 15 children. The first two groups were 14-15 years old and second three were 9-10 years old. They did not have any problems interacting with the simulations. The children found the animation realistic. Younger groups had problems understanding the conclusions which they derived from "Numbers." Therefore we considered our interactive application to be appropriate for children older than 10 years (at this age they start learning physics in school). We also tested different operating systems. The application ran without any problems under either Linux or Windows. We found that our multimedia CD ROM was very interesting for children and we will continue its development and testing with the goal to help children to learn physics. Demo version of our application is available via http://www.sccg.sk/~kovarova/projects.

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