

TOOLS FOR SCIENTIFIC THINKING - VIRTUAL LABORATORY FOR TEACHING PHYSICS

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Abstract. In the present work, we describes the software developed by the authors, designed and implemented for teaching and learning physics. The program combines a simple graphical user interface with a powerful engine that simulates the fundamental laws of Newtonian mechanics, requiring no programming skills. As the example, we present the result obtained at study the mathematical pendulum. The results are in excellent agreement with the theoretical predictions. Versatility and usability of the computer program make it suitable to be used in a virtual physics laboratory.

Key words: virtual laboratory, software, mathematical pendulum, physics education.

1. INTRODUCTION

The presence of a virtual laboratory is a natural consequence of the gradual development and implementation of cutting edge digital technologies in Physics classes by which the virtual component of learning by experiment and independent activity has acquired a defining importance. Physics experiments simulation through an application is especially useful when the studied physical phenomena cannot be fully explored through normal laboratory instrumentation [1-3]. We may also notice the utility of the virtual physics laboratory in the understanding of the physics concepts from simple to complex. As examples of complex systems described by mean of computer simulations, we may mention here giant magnetoresistance [4], scanning electron microscope [5], complex models of polymers [6-8] or liquid crystals [9-11].

Not only teachers, but also students can be involved in the design of the virtual experiments, which significantly increases their ability to handle physical and mathematical concepts. Using simulations to study physics as part of the learning activities based on the investigation has advantages presented in literature

[12].

So far, educational software has been designed and implemented for teaching and learning physics at an advanced and modern level, both in elementary schools and in universities [13-14]. The present work briefly describes the software developed by the authors in order to study the mathematical pendulum. The mathematical pendulum is one of the simplest, but important device used in both theoretical and experimental physics. Developing and implementing of the physics educational software for the laboratory simulations has a number of advantages such as: compensating the lack of expensive equipment and appliance; even in the absence of a sufficient number of laboratory sets, the students may do simultaneous experiments; performing real time experiments simulation which are unfeasible in laboratory conditions or for security reasons; providing controlled errors that occur during experimental measurements; computer modeled laboratory works are reproducible under any circumstances, irrespective of the duration or external influences.

Virtual experiments may stimulate students' interest, but do not guaranteed improving of the understanding of fundamental concepts. However, teaching-learning process optimization can be achieved, by their rational use and by combining classical instruments and virtual resources [15].

2. THE METHOD

Interactive Interface Physics in the study of mathematical pendulum IP combines a simple graphical user interface (GUI) with a powerful engine that simulates the fundamental laws of Newtonian mechanics, requiring no programming skills (Fig.1).

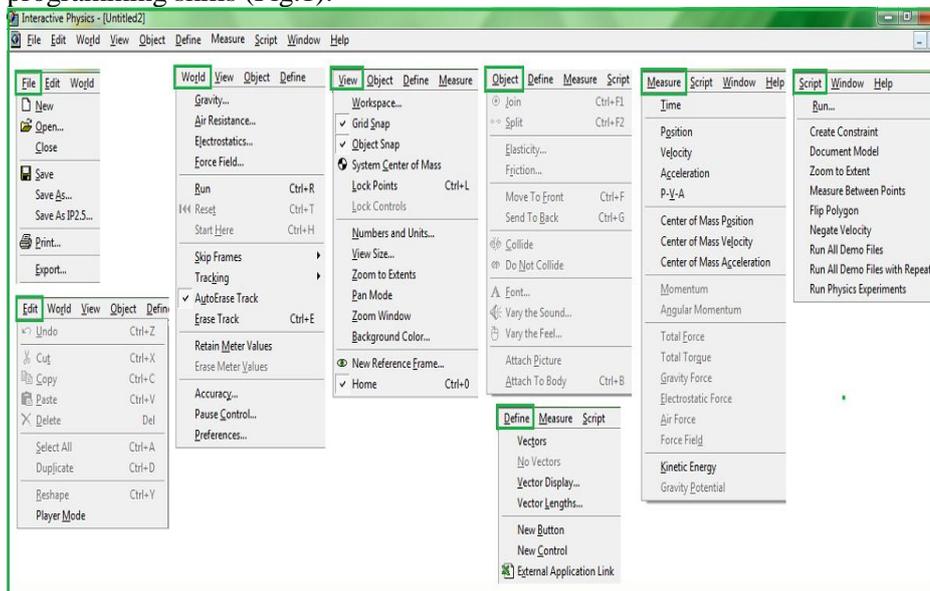


Fig. 1 - Interactive Physics graphical interface. The colored versions can be accessed at <http://www.infim.ro/rfp/>.

The user can introduce elements such as springs, pulleys, joints etc. IP has the ability to simulate interactions at all levels such as collisions, gravity, air resistance and electrostatic interactions. Physical quantities such as speed, acceleration, momentum, kinetic energy and friction force can be measured during the simulation. The user can display the measured values as numbers, vector displays, graphics and animated views (Fig.2).

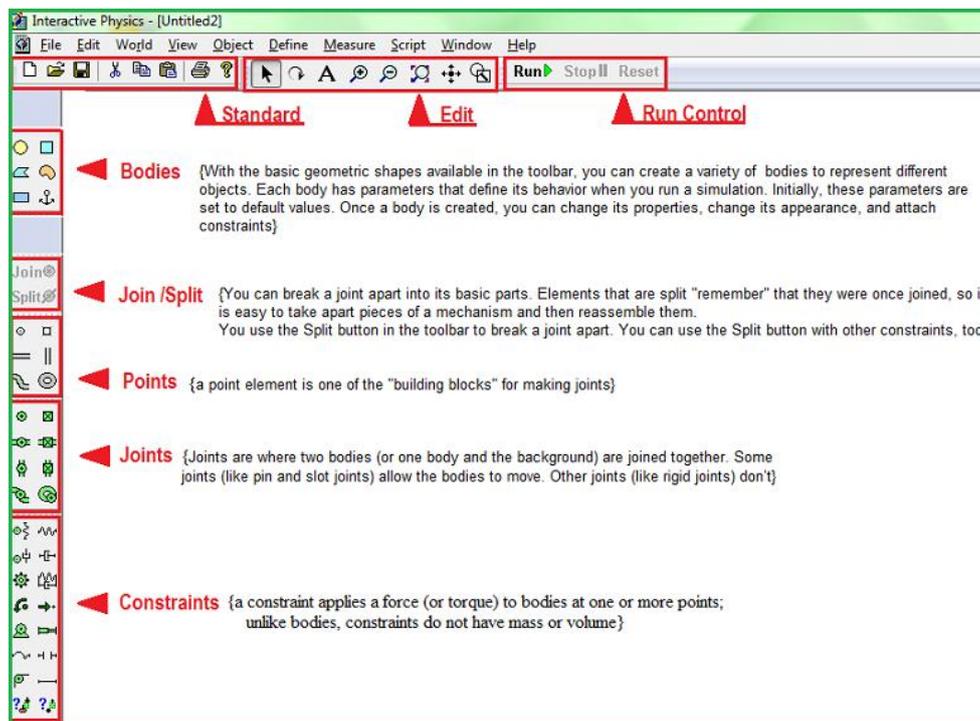


Fig. 2 - Interactive Physics menu and work instruments. The colored versions can be accessed at <http://www.infim.ro/rfp/>.

For more complicated physics conditions, it is impossible to find exact the solutions [16-18]. IP uses numerical methods to describe the motion of the mechanical systems. The solution of the problem is obtained by numerical integration, as in the cases much more elaborated of molecular dynamics simulations [16-18]. Like in the previously mentioned problem, time is discretized so that IP calculates the movement and forces, but also ensures that all restrictions are completed. Specifically, IP finds the instantaneous acceleration of an object and uses this acceleration to calculate the speed and position at a later time. There are several methods of numerical integration to calculate new values of velocity and position at a later time [16].

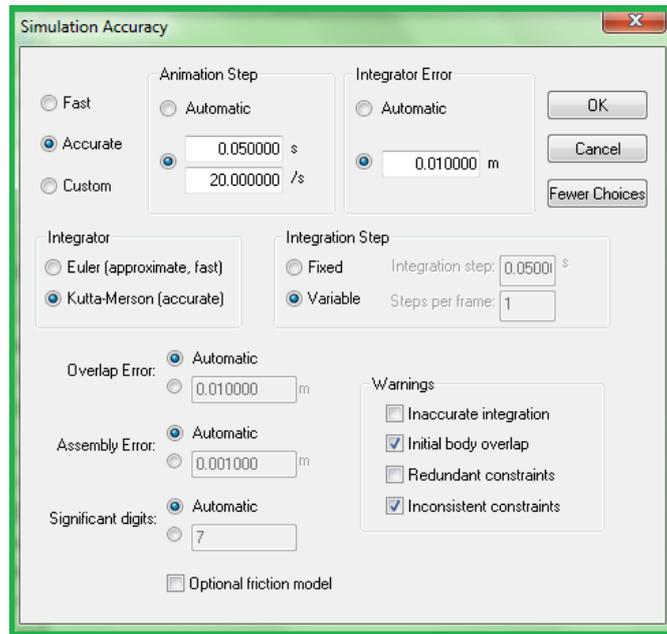


Fig. 3 - Setting the simulation accuracy in the Interactive Physics interface. The colored versions can be accessed at <http://www.infim.ro/rpp/>.

IP Version 9.0.3.806 used in the present study has a window in which the user can decide the integration method, Euler or Kutta-Merson, the integration speed, the animation speed and other significant values. An important feature is that IP has the ability to automatically choose the appropriate time values, as well as the option to track the simulation errors (Fig. 3).

3. MATHEMATICAL MODEL

The mathematical pendulum is a mass point attached to the end of a wire without weight (Fig. 4) [19].

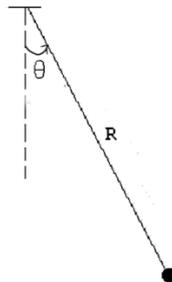


Fig. 4 - Schematic representation of the mathematical pendulum

The following variables are used:

- θ = angle made by wire with vertical;
- R = the wire length;
- T = the wire tension;
- m = the pendulum mass;
- g = the gravitational acceleration.

The net torque is $\tau = I \cdot \alpha$, where

- τ = net torque;
- I = the moment of inertia;
- $\alpha = \theta''$ = angular acceleration.

The moment of inertia relative to the rotation axis is $I = mR^2$. The torque may be calculated as the cross product between the position vector and the force. The torque component due to the gravity is $\tau = -R \cdot m \cdot g \cdot \sin \theta$. So, we have

$$-R \cdot m \cdot g \cdot \sin \theta = m \cdot R^2 \cdot \alpha$$

which may be rewritten as

$$\theta'' = -\frac{g}{R} \sin \theta \quad (1)$$

This is the equation of motion of the mathematical pendulum [19, 20].

For small oscillations ($\theta < 5^\circ$) we use the approximation $\sin \theta = \theta = x/R$. The equation of motion becomes:

$$\theta'' = -\frac{g}{R} \cdot \theta \quad (2)$$

The above equation is a linear differential equation which solution is [19, 20]

$$\theta(t) = \theta_0 \cos(\sqrt{g/R} \cdot t)$$

where θ_0 is the angular elongation and t is time. The period of the movement is

$$T = \frac{2\pi}{\sqrt{g/R}}$$

and the frequency:

$$\mathcal{F} = \frac{1}{2\pi} \sqrt{g/R}$$

4. VIRTUAL EXPERIMENT

In this section, we present a screen capture made on the IP interface. The IP designed experiment has as input parameters: m (the mass of the ball), L (the length of wire) and g (the gravitational constant). The simulation conditions are ideal: the wire does not have mass, it is inextensible, there is no resistance from air, there are no electrical interactions etc. In addition, the amplitude of the oscillations fulfill the condition that the deviation from the vertical are less than 5 degrees (isochronism condition).

From Fig. 5, we may see that the place of the experiment can be chosen on

the Earth, on the moon or another planet, using the cursor which can select the value of the gravitational acceleration.

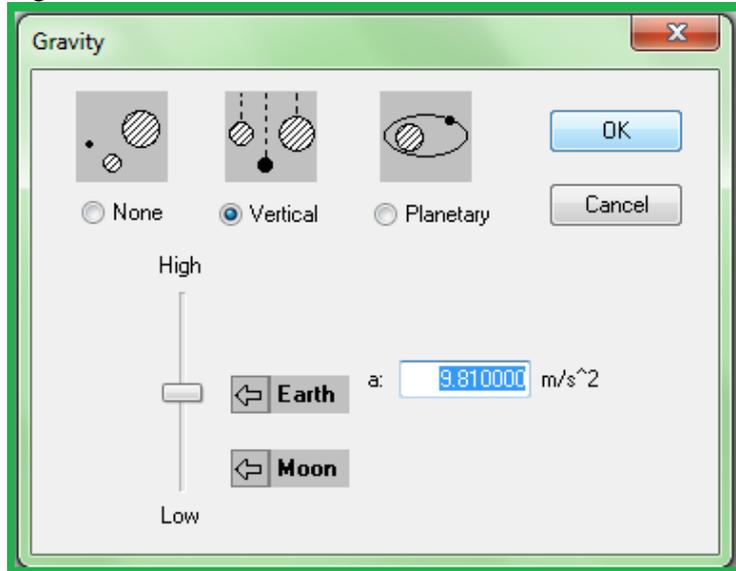


Fig. 5 - Interface for choosing the gravitational constant. The colored versions can be accessed at <http://www.infim.ro/rfp/>.

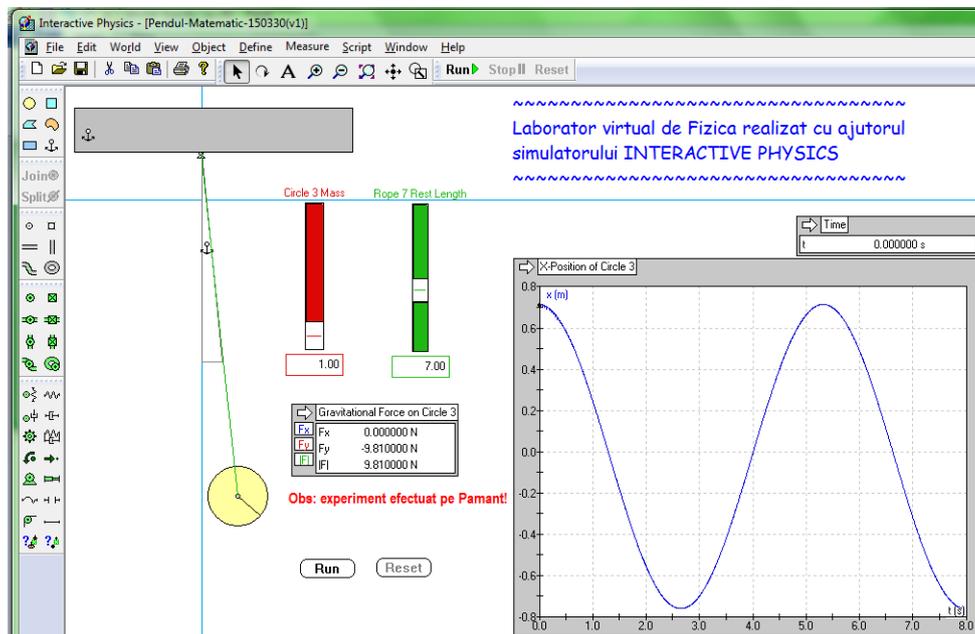


Fig. 6 - Experiment performed on the Earth. The colored versions can be accessed at <http://www.infim.ro/rfp/>.

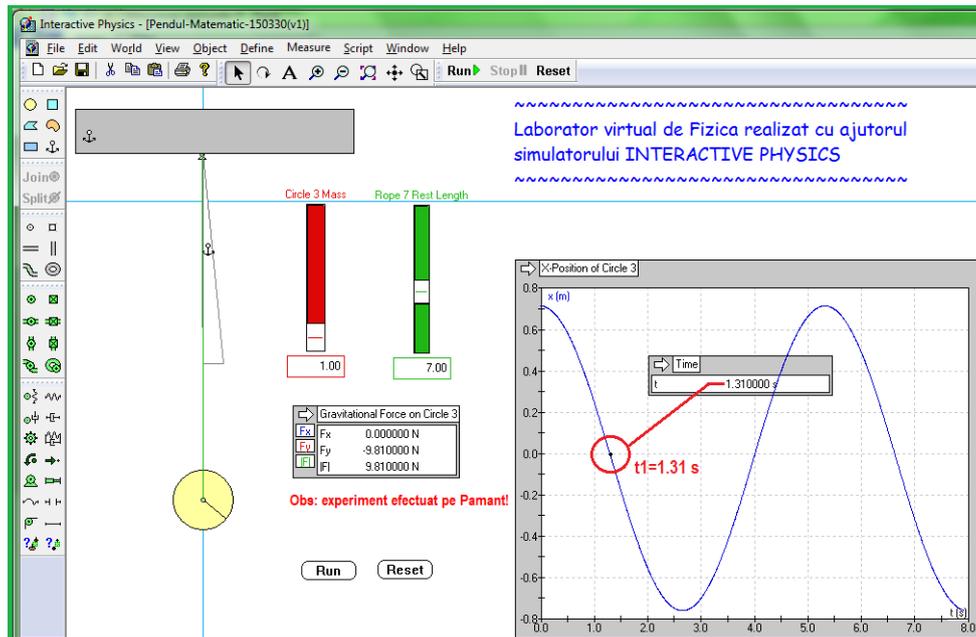


Fig. 7 - Snapshot in the intermediate time t_1 . The colored versions can be accessed at <http://www.infim.ro/rfp/>.

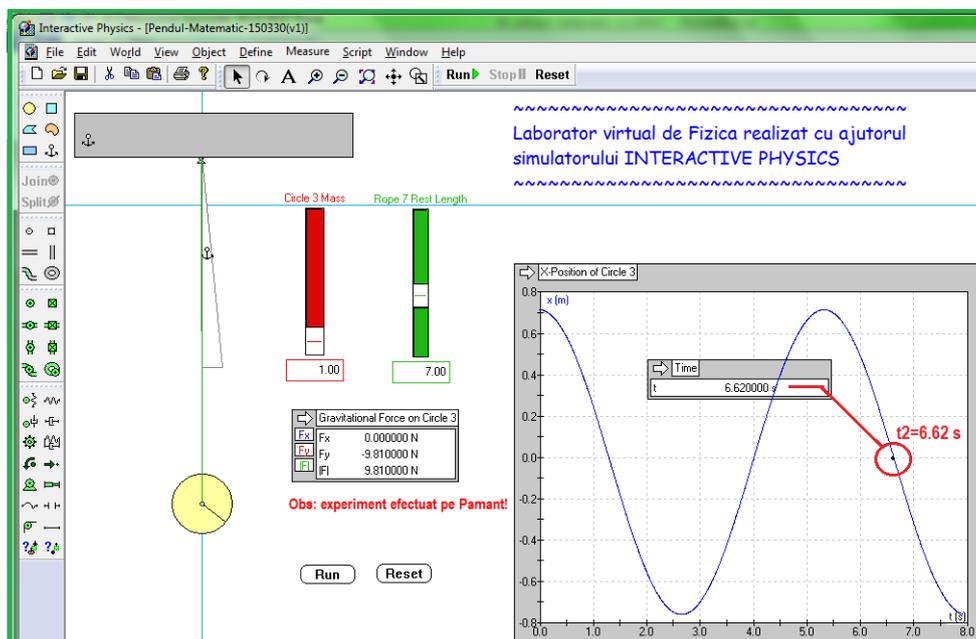


Fig. 8 - Snapshot in the intermediate time t_2 . The colored versions can be accessed at <http://www.infim.ro/rfp/>.

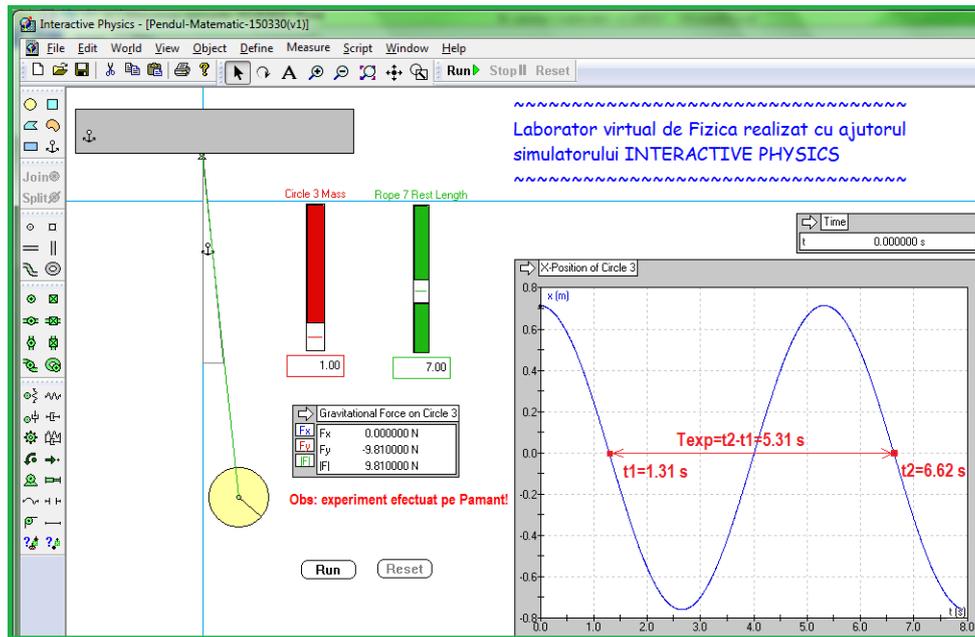


Fig. 9 - Experimental period of oscillation. The colored versions can be accessed at <http://www.infim.ro/rp/>.

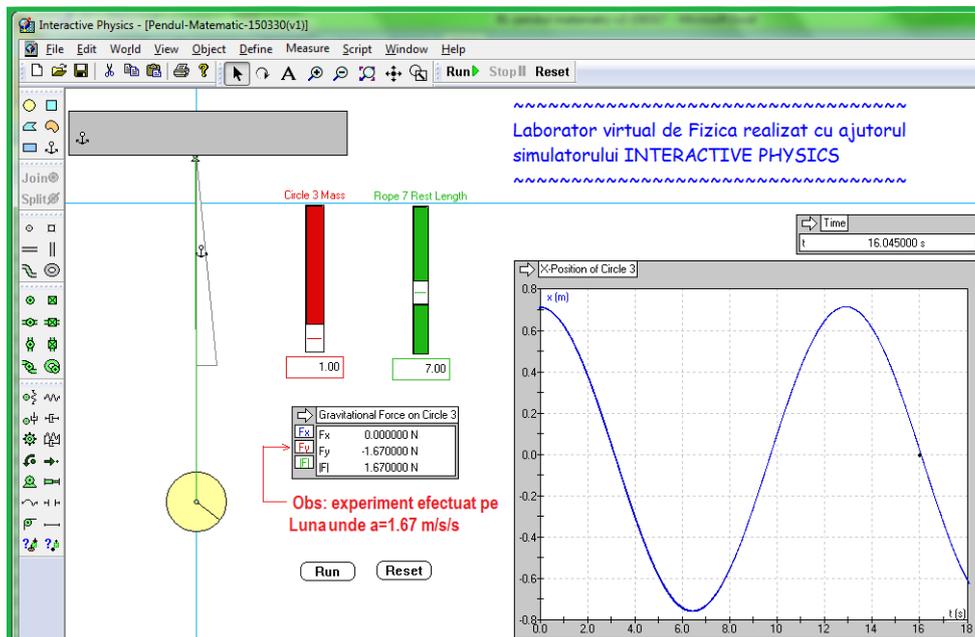


Fig. 10 - Experiment on the Moon. The colored versions can be accessed at <http://www.infim.ro/rp/>.

After collecting data and calculation of the period, we check the dependence of T_{exp} on $\sqrt{1/g}$ (Fig. 11) and \sqrt{L} (Fig. 12)

Table 1
Values of T and $\sqrt{1/g}$ collected from simulation

L(m)	g(m/s ²)	t ₁ (s)	t ₂ (s)	$\sqrt{1/g}$ (s/ \sqrt{m})	T _{exp} (s)
7	1.00	4.105	20.735	1.000	16.63
7	1.23	3.690	18.690	0.900	15.00
7	1.56	3.275	16.585	0.800	13.31
7	1.67	3.165	16.045	0.774	12.88
7	2.04	2.870	14.515	0.700	11.64
7	2.78	2.455	12.435	0.600	9.98
7	4.00	2.045	10.365	0.500	8.32
7	6.25	1.635	8.295	0.400	6.66
7	9.81	1.310	6.620	0.319	5.31
7	20.00	0.915	4.635	0.224	3.72

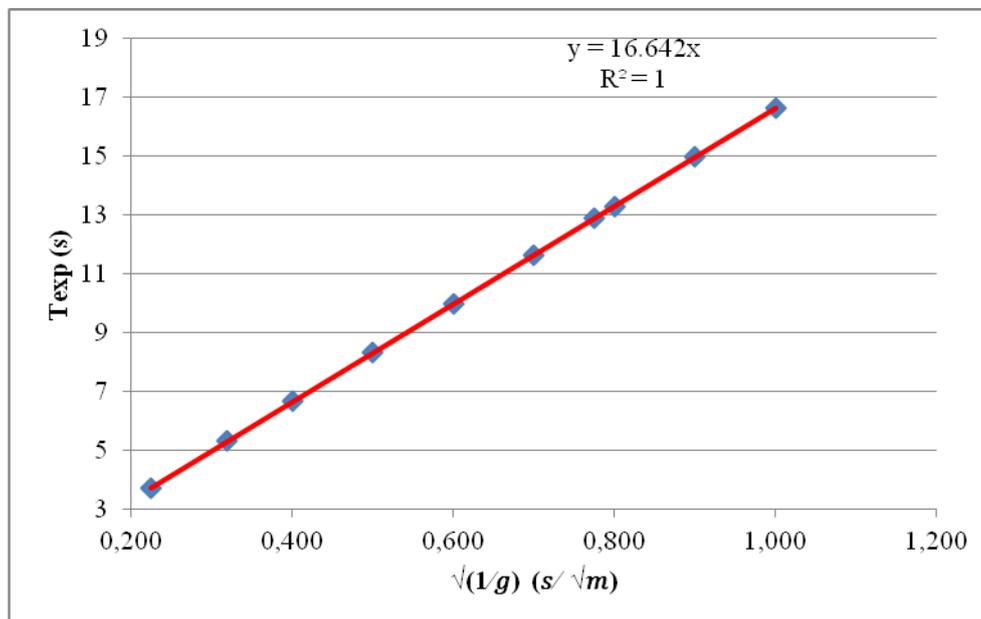


Fig. 11 - Dependence of T on $\sqrt{1/g}$. The colored versions can be accessed at <http://www.infim.ro/rrp/>.

Table 2
Values of T and \sqrt{L} collected from simulation

L (m)	g (m/s ²)	t ₁ (s)	t ₂ (s)	\sqrt{L} (\sqrt{m})	Texp (s)
10.00	9.81	1.570	7.920	3.162	6.350
9.50	9.81	1.535	7.720	3.082	6.185
9.00	9.81	1.480	7.510	3.000	6.030
8.50	9.81	1.440	7.300	2.915	5.860
8.00	9.81	1.395	7.085	2.828	5.690
7.50	9.81	1.350	6.850	2.739	5.500
7.00	9.81	1.310	6.620	2.646	5.310
6.50	9.81	1.255	6.375	2.549	5.120
6.00	9.81	1.205	6.125	2.449	4.920
5.50	9.81	1.155	5.860	2.345	4.705
5.00	9.81	1.100	5.585	2.236	4.485

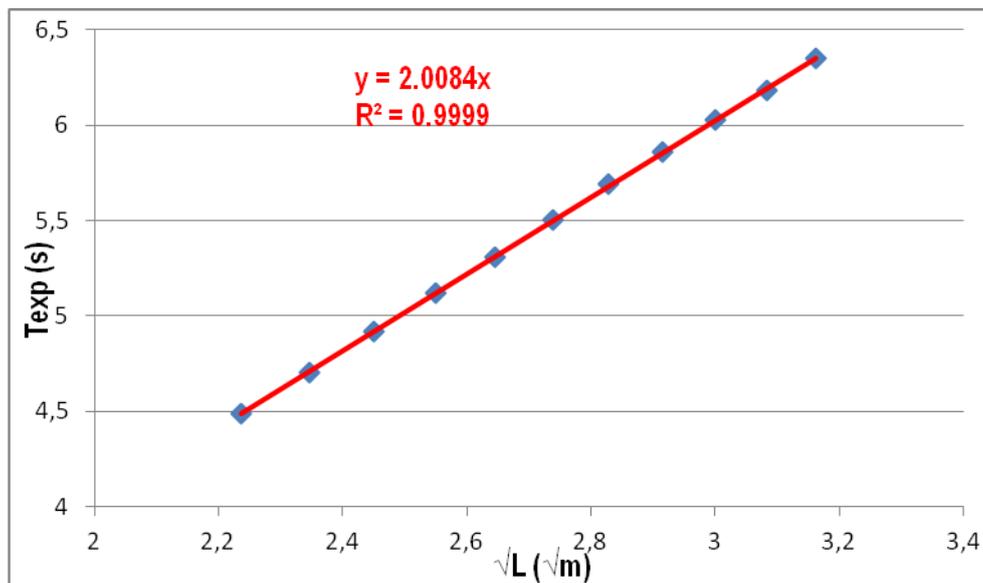


Fig. 12 - Dependence of T on \sqrt{L} . The colored versions can be accessed at <http://www.infim.ro/rfp/>.

From graphs in Fig. 11 and Fig. 12 a dependence between the period T and mass m was not revealed, but a linear dependence $T \sim \sqrt{L}$ and $T \sim \sqrt{1/g}$ was

obtained.

Comparing the simulation results with those theoretically obtained in classical physics, we conclude that the exact form of the relation $T = 2\pi\sqrt{L/g}$ is confirmed by the virtual experiment (IP).

5. CONCLUSIONS

Interest in computer-based learning, especially in the use of virtual reality simulations is increasing rapidly. This article has presented the computer applications designed for didactic purposes in physics education. The simulation and virtual laboratories of real experiments are undoubtedly the most important items of these applications. Among the various possibilities to use computers in physics teaching, we chose computer simulations because it allows students to interact with the construction process and scientific knowledge analysis, promoting a better understanding of physical concepts.

REFERENCES

1. S. Moraru, I. Stoica, F.F. Popescu, Rom. Rep. Phys., **63**(2), 577–586, (2011).
2. C. Kuncser, A. Kuncser, G. Maftai, S. Antohe, Rom. Rep. Phys., **64**(4), 1119–1130, (2012).
3. C. Kuncser, S. Antohe, Rom. Rep. Phys., **66**(4), 1226–1235, (2014).
4. F. Iofciu, C. Miron, M. Dafinei, A. Dafinei, S. Antohe, Rom. Rep. Phys., **64**(3), 841–852, (2012).
5. L. Dinescu, M. Dinica, C. Miron, E.S. Barna, Rom. Rep. Phys., **65**(2), 578–590, (2013).
6. L. Georgescu, C. Berlic, C. Miron, Revista de Chimie, **55**(5), 317-319, (2004).
7. C. Berlic, L. Constantinescu, Revista de Chimie, **55**(11), 910-913, (2004).
8. V. Barna, C. Miron, C. Berlic, E.S. Barna, Mat. Plast., **40**(4), 168-170, (2003).
9. C. Berlic, V. Barna, Mol. Cryst. Liq. Cryst., **549**(SI), 140-149, (2011).
10. C. Berlic, V. Barna, Opt. Express, **18**(23), 23646-23656, (2010).
11. C. Berlic, V. Barna, J. Optoelectron. Adv. M., **12**(6), 1427 - 1432, (2010).
12. D. Marciuc, C. Miron, Technology Integration of Geogebra Software in Interdisciplinary Teaching, Proceedings of the 10th International Scientific Conference "eLearning and Software for Education" Bucharest, **3**, 280-287, (2014).
13. I. Stoica, S. Moraru, C. Miron, Second World Conference on Educational Sciences (WCES 2010), Istanbul, February 4-8, Published by Elsevier Ltd. in Procedia - Social and Behavioral Sciences, **2**(2), 4407-4411, (2010).
14. A. Murello, E. Milotti, Eur. J. Phys., **35**(1), 015014, (2014).
15. M. Garabet, C. Miron, The 6th International Conference on Virtual Learning – Virtual Reality, (ICVL 2011) October 28-29, Cluj-Napoca. Proceedings of the 6th International Conference On Virtual Learning, 181-184, (2011).
16. D. Frenkel, B. Smit, *Understanding Molecular Simulations. From Algorithm to Applications*, Academic Press, New York, 2002.

17. M.P. Allen, D.J. Tildesley, *Computer Simulation of Liquids*, Oxford University Press, 1989.
18. D. P. Landau, K. Binder, *A Guide to Monte Carlo Simulations in Statistical Physics*, Cambridge University Press, 2000.
19. A. Hristev, *Mecanică și Acustică*, Ed. Didactică și Pedagogică, București, 1984 (in Romanian).
20. A.P. Arya, *Introduction to Classical Mechanics* (2nd Edition), Addison-Wesley, San Francisco, 1997.