Non-traditional Use of Computer Simulation "My Solar System" in Inquiry-based Teaching

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Abstract

Teaching method plays crucial role affecting students' motivation to learn physics. There are many innovative strategies for teaching physics. One of them is inquiry-based teaching. Investigative approach in physics teaching is very effective tool that gives students the opportunity to try their self-procedures used by scientists in investigation of the real problems. The appropriate object of examination can be an interactive computer simulation. The simulation "My Solar System" developed in University of Colorado Boulder was used for this purpose. Students of grammar school were invited to examine this own "pocket universe". The program simulates movement of 2 – 4 gravitationally bound bodies. The students can measure position, velocity and mass of the bodies versus time. The paper describes step by step how to work with students. The students' activities and obtained skills are described.

1. Introduction

In the last decades Slovak universities feel a decline of interest in engineering study. The cause is not just that these professions are under-appreciated (the most popular jobs are economics, management, law, medicine, etc.), but also in the fact that students have insufficient knowledge and competence in mathematics and physics, which are a necessary prerequisites for successful studying the engineering disciplines. Although the professional level of the best graduates of technological faculties has increased slightly, the average graduate has worse outcomes and competencies in comparison with state of twenty years ago.

To improve this situation, the Ministry of Education adopted in 2008 school reform, which aimed, inter alia, to achieve a greater degree of creativity of students and reduce memorizing encyclopedic data. According to reform, schools were given the opportunity to split some of the teaching hours between subjects in its discretion, divide the class into two groups for laboratory exercises, but, on the other hand, the number of teaching hours for mathematics and physics was significantly reduced. Till yet, in the most primary and secondary schools physics is taught by traditional methods. Modern, efficient methods of teaching are not very extending. Therefore, the issue of increasing the effectiveness of physics teaching is still very important.

Teaching method plays crucial role affecting students' motivation to learn physics. There are many innovative strategies for teaching physics and large number of publications confirms its effectiveness [1]. The fundamental difference between the traditional approach (teacher gives students ready knowledge, and they receive their passive) and modern methods lies in the fact that modern methods require students to work hard and think throughout the lesson because they have to obtain new knowledge alone, or under the guidance of a teacher. In the past decades several new approaches appeared, such as investigative science learning environment - ISLE [2] problem-based learning approach - PBL [3], research based learning method [4, 5], project based learning [6, 7], inquiry based teaching [8 - 10] scientific inquiry method [11, 12] and other. All these new strategies are similar to each other - their common goal is to help students develop understanding of the nature of physics, to support their creative thinking and to deepen their understanding of concepts.

2. Computer simulation in teaching

Physics is an experimental science and therefore experiment play very important role in the teaching. Both, demonstration experiments as well as class experiments have to be an indispensable part of the teaching. However, sometimes can be helpful use a computer simulation instead of experiment. The advantage of computer simulation is that reasonably simplifies physical reality, draws attention to the essential characteristics of physical phenomena and allows visualization also of those phenomena, which is experimentally very difficult if not impossible to observe. A lot of research shows a high efficiency of the use of applets and computer simulation in the teaching [13, 14]. Interactive simulation allows students to change the parameters of the phenomenon and observe the changes brought about, and so better understand the nature of the phenomenon. Therefore, such simulations are very effective tools for inquiry-based teaching.
Investigative approach in physics teaching is very preferable way how to make physics more interesting and attractive. In this approach, the students should, under the guidance of a teacher, investigate some physical phenomenon. The teacher asks students questions and guides them on the path to solving the problem. The students observe investigated phenomena, analyzed them and looking for pattern. They should be able to choose suitable parameters describing the phenomenon and measure them. Then, if it is possible, evaluating dependencies between physical variables and formulate it mathematically.
Of course, such approach requires several conditions: Studied physical phenomenon must be relatively simple, the dependence between parameters must be easy to express mathematically. Necessary experimental apparatus must be relatively inexpensive and available in multiple exemplars, because students must work in small groups (2 – 3 people). Desirable that the apparatus could be easily modified and allow to simply change the parameters of the experiment, so that students can examine different aspects of the phenomenon. Because the financial resources and experimental facilities of schools are limited, we were looking for a way to dispense with expensive apparatuses.

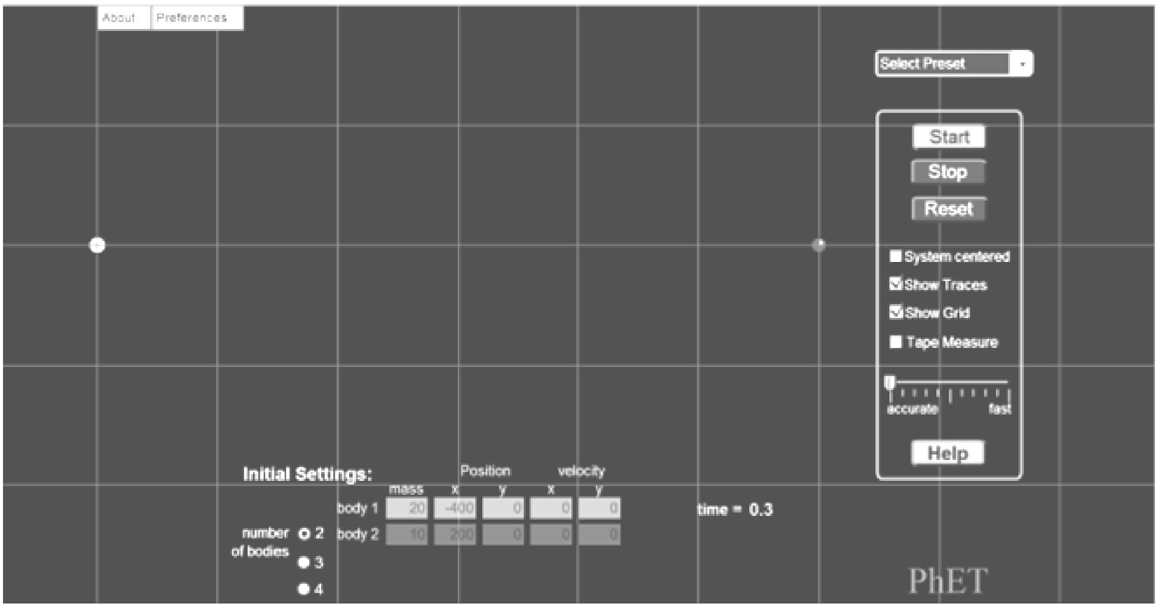

Figure 1. My Solar System

Therefore, we proposed to use instead of the real experiment to work with computer simulation. The appropriate object of examination can be an interactive computer simulation “My Solar System” (MSS) developed in University of Colorado Boulder [15]. The simulation is freely accessible and each student can work with it at home on his PC. The program simulates movement of 2 – 4 gravitationally bound bodies in the XY plane. Program allows the user to set mass of the body (arbitrary positive number) place the body to a point of arbitrary coordinates x, y (only integer) and enter his initial velocity vector v_x, v_y (only integer). The clock shows actual time (Fig.1).

Simulation uses its own units; we named them 1T (tik) for time, 1L (lap) for length and 1M (mot) for mass. Button START run the motion and button STOP stop it. When START button is pressed again, it causes continuance of movement; button RESET returns the system to the initial state. When motion is stopped and cursor is put on the body position, program shows the coordinates and velocity components of the body. Similar to real experiment, these results are not absolutely precise. Accuracy of measurement of time, length and velocity is ±0.1 T, ±0.1 L and ±0.1 L/T respectively. Only mass we can know absolutely accurate. For the proper work with the program it is necessary to set off the SYSTEM CENTERED mode and set the calculation mode to ACCURATE.

3. Work with computer simulation “My Solar System”

The simulation MSS gives large possibility to work with students. There is a variety of tasks, from the simplest ones to complex tasks requiring independent investigative work of students. First of all, the students should be familiar with the program and learned to work with it. Students were encouraged to examine this own "pocket universe". In the next section we will describe briefly how it could look like teacher work with students of guided scientific inquiry.

The instructions were as follows: Imagine that you have just created the universe and you have chosen appropriate units of time, mass and length, so you can examine its properties. We will start with 2 bodies of similar mass (20 M and 10 M, or 20M and 30 M, 10 M and 50 M and so on). It is advantageous if each group of students will select a different combination of masses. Place the bodies on the x-axis, for example into the points (-400, 0) L and (100, 0) L. Initial velocity of both bodies should be zero. Start the program and observe the movement. Reset and start again. Start and stop the motion repeatedly and measure their velocity and position in various stages of movement. Write down intermediate values of time, velocity and position of both bodies. It is preferable to write it into Excel form. Find the position of a point where the bodies collide. How the ratio of the speed of bodies depends on their masses? Calculate (preferably in Excel) the distance traveled by each of the bodies and find how their ratio depends on the masses.

Some examples of this task are shown in Tab.1. In the second part of the table there are calculated values of ratio s_2/s_1 and v_2/v_1. Expected conclusion of students, formulated in words or formula is that the ratio of velocities is equal to the reciprocal ratio of their masses, i.e.

$$\frac{v_1}{v_2} = -\frac{m_2}{m_1} . \quad (1)$$

Of course, our “experimental” data are not quite accurate, as it exhibits measurement uncertainty. As a next step we will discuss students’ observations and conclusions. Edit the formula (1) so, that on the left side of the equation will be only variables related to the first body and on the right side related to the second body.

$$m_1 v_1 = -m_2 v_2 \ . \quad (2)$$

Table 1. Measurement of velocities

t, T	0	7,5	9,3	12	14	14,6
m_1, M	50					
x_1, L	-400	-388,3	-381,3	-366,5	-350,4	-343,7
v_1, L/T	0	3,3	4,4	6,7	9,9	11,8
m_2, M	10					
x_2, L	100	41,3	6,7	-67,5	-147,8	-181,5
v_2, L/M	0	-16,5	-21,9	-33,5	-49,5	-58,9
s_1, L	0	11,7	18,7	33,5	49,6	56,3
s_2, L	0	-58,7	-93,3	-167,5	-247,8	-281,5
s_2/s_1		-5,02	-4,99	-5,00	-5,00	-5,00
v_2/v_1		-5,00	-4,98	-5,00	-5,00	-4,99

Now we can define some physical quantity describing the movement of the body as a product of its velocity and mass – we name it momentum H = m.v. What is the physical meaning of equation (2)? At any point of time is the momentum of first body the same size but opposite direction as the momentum of second body. The sum of both momentums is zero all the time. Therefore, after collision the resulting body will have zero momentum, and, as a result zero velocity. We can verify this by letting the simulation runs into collision of bodies.

How will change the results of the experiment, when the initial velocity of the first body will not be zero, and will have, for example, value of v_0 = 10 L/T in x-axis direction? Trace the change in momentum over time. After analogous procedure we obtain the result

$$m_1 v_1 = m_1 v_0 - m_2 v_2 \,. \tag{3}$$

So, step by step we will guide our students to the concept conservation of momentum, momentum as vector quantity and even to the concept of force and Newton's law of force. Why body changes its momentum? Because other body acts on it. We can define new physical quantity named force as a measure of acting of one body to other. Examine how quickly changes the momentum of the body. Repeat our first experiment with masses twice smaller. We can see that change of momentum is slower. Thus, it is reasonable to define force as a measure of change of momentum in time

$$F = \frac{\Delta H}{\Delta t} \,. \tag{4}$$

The next situation, in which we can use MSS simulation, is measurement of acceleration and investigation how it depend on masses and mutual distance of bodies. Let choose the mass of first body m_1 = 0.001 M and second body m_2 = 100 M with initial velocities equal zero. As we know from first experiment, the velocity of second body will be 100 thousand times smaller than velocity of first one, and so we can neglect it. Second body will stay in its initial position. Place the first body into point (0, 0) L and second body into point (1000, 0) L. Run the program and stop it after few T. How we can measure initial acceleration of the first body? We expect that students know the formulas for uniformly accelerated motion and therefore they propose measuring of acceleration either from formula $s = ½ a. t^2$ or from formula $a = v/t$ (initial velocity is zero). Of course, it is necessary to discuss the precision of both methods. The students were encouraged to measure the initial acceleration of first body for various initial distances between both bodies (for example 600 L, 800 L, 1000 L and so on). The example of obtained results is shown in Tab.2.

Table 2. Measurement of acceleration

x_2, L	t, T	x, L	v, L/T	a=v/t, LT^{-2}	$a=2x/t^2$, LT^{-2}	R, L	$a.R^2$, L^3T^{-2}
600	3,5	17,3	9,9	2,829	2,824	591	988423
800	7	38,8	11,3	1,614	1,584	781	974316
1000	8,9	40,5	9,2	1,034	1,023	980	986934
1200	10,5	38,3	7,4	0,705	0,695	1181	975769
1400	12,2	38,1	6,3	0,516	0,512	1381	980546
1600	17,4	59,5	7	0,402	0,393	1570	980541
1800	19,4	58,6	6,1	0,314	0,311	1771	981118
2000	21,9	60,8	5,6	0,256	0,254	1970	987767
2200	24,1	60,4	5,1	0,212	0,208	2170	987754
2400	25,6	57,3	4,5	0,176	0,175	2371	985897
2600	27,9	57,8	4,2	0,151	0,149	2571	988428
2800	29,6	56,4	3,8	0,128	0,129	2772	987718
3000	33,2	61,7	3,7	0,111	0,112	2969	984729

Expected conclusion of students is that both method of the acceleration measurement give very similar values. To analyze the dependence of the acceleration on the distance we have to construct a graph (Fig.2). Distance R between the bodies was calculated as an average value of initial and final distances, i.e. $R = x_2 – ½ x$.

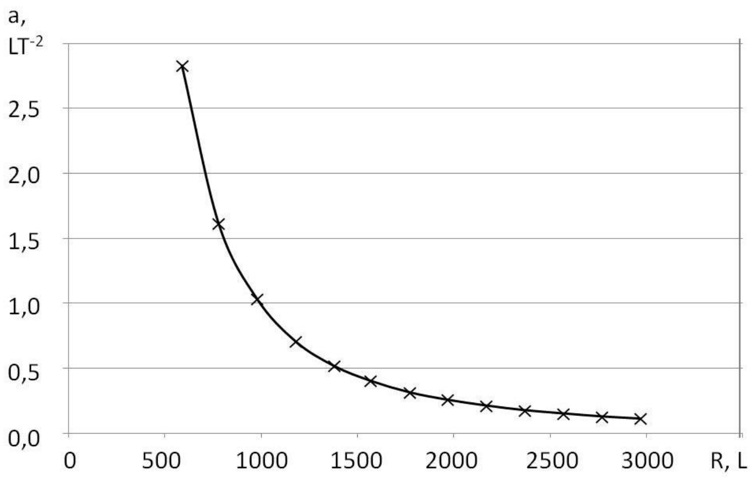

Figure 2. Dependence acceleration on distance of bodies

As we can see from Fig.2, acceleration decreases with increasing distance. For more detailed analysis we have to calculate the product of a.R and then expression $a.R^2$ for all data from Tab.2. The second attempt is successful (last column in the table) and therefore we can conclude that acceleration is inversely proportional to the square of its distance. Now we have to investigate acceleration dependence on mass of first, resp.

second body. We make some acceleration measurements for m_2= 100 M, 150 M, 200M, 250 M and so on. All other parameters have to be constant. The conclusion is that a is proportional to m_2. Analogously we investigate dependence a on m_1 – result is that acceleration of first body is independent on its mass. Finally, the acceleration dependence can be described by formula

$$a_1 = G\frac{m_2}{R^2} \ , \qquad (5)$$

where constant of proportionality G can be calculated from the last column of the Tab.2. It has value G = 9838 $L^3M^{-1}T^{-2}$. From this result we can easily deduce the gravitational law.

The simulation MSS gives us a lot of other possibilities for guided scientific inquiry. For example, if the students are familiar with concept of energy, we can calculate the kinetic energy of bodies from the values in Tab.1 and investigate how the sum of the kinetic energy depends on mutual distance of bodies. The dependence of kinetic energy on the mutual distance of bodies is shown on the graph in Fig.3.

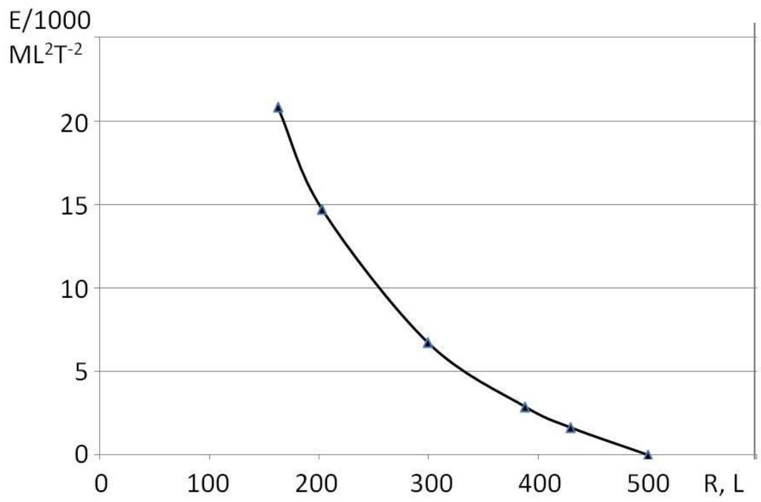

Figure 3. Dependence kinetic energy on distance of bodies

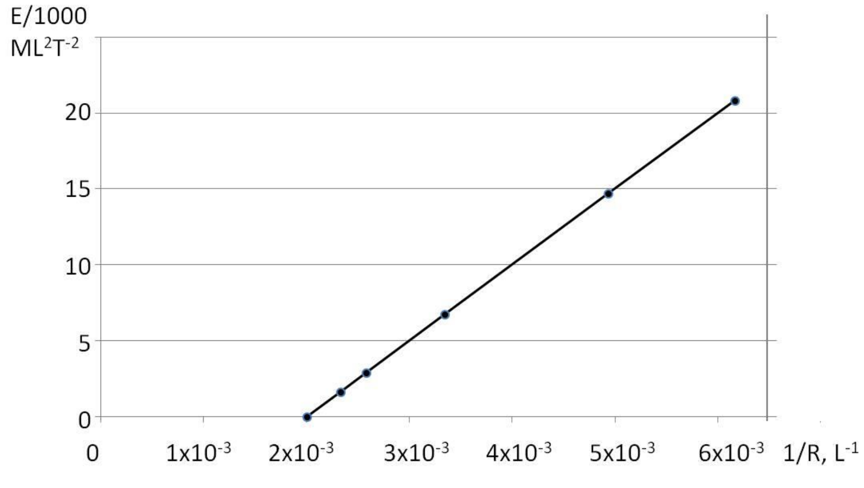

Figure 4. Dependence kinetic energy on inverse of the distance of bodies

Dependence E versus 1/R is shown on Fig.4. As we can see, it is a linear dependence. Therefore we can calculate the parameters of this dependence as follows:

$$E_{kin} = E_0 + \frac{K}{R} \qquad (6)$$

where E_0 = -10007 ML^2T^{-2} and K = 5,003 x 10^6 ML^3T^{-2}. From this result we can easily obtain formula for potential energy in gravitational field and also gravitational constant G = 10006 $L^3M^{-1}T^{-2}$. This result is slightly different from previous obtained from acceleration measurements.

4. Conclusions

Modern teaching methods are very effective way how teach science, especially physics more interesting and effectively. Investigative science learning and inquiry based teaching proved its ability to give students more complex knowledge and skills. The understanding of natural law is much deeper and more permanent than a traditional learning. Although the inquiry based teaching gives very good outcomes, most teachers use the traditional method of teaching. There are several reasons why the modern methods of learning are not frequently used.

1. Curricula require teachers take a large amount of material in a relatively small number of lessons. Therefore they have not enough time for active work with students
2. The teachers are not good paid and therefore most of them have a side jobs or extra lessons.
3. Teacher's education is based on traditional teachings; they are not adequately prepared for modern learning methods.

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