Application of ICT Technology in Physics Education: Teaching and Learning Elementary Oscillations with the Aid of Simulation Software

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Abstract—**In the present study we employ a combination of laboratory exercises and simulation. In particular we studied the case of teaching mechanical oscillations to undergraduate students of Polytechnic and Pedagogical departments. Simulations were performed using a general purpose package, MATHEMATICA®, which is widely employed in our departments, and presents some important advantages such as ease of writing mathematical relations, small extent of programs necessary for the solution, ease of creating graphical representations/animations. In the employed process an experimental setup of the physical system is constructed and then using a general purpose package students construct a model of the system that already know from the laboratory experiments. Using these models students produce solutions for various initial conditions, graphical representations of the results as well as animations corresponding to the time evolution of the system. The results show that the above process offers the students many different representations of the physical problem leading to a better understanding, contribute to the development of critical spirit and to the familiarization with the use of ICT.**

Index Terms—**Interactive learning, Models of oscillators, animation, Mathematica® .**

I. INTRODUCTION

The teaching of physics in the Academic Departments combines lectures and laboratory practice where experiments play an essential role. Teaching is considered successful if students have acquired an ability to criticize, creative thinking as well as skills of using experimental and calculating techniques to comprehend the structure and operation of natural world in a variety of scales.

A fundamental question of Science Education constitutes the search of the most optimal instructive approach. Such an approach will have to create conditions of participation in the training process and lead to the essential and in-depth comprehension of cognitive objects which introduces. For the majority of physics professors the most optimal instructive approach is an experimental one. However, such approaches are not exempted of problems [1] with regard to the comprehension and learning. The success of an experimental approach depends on how much the experiment is harmonized functionally with the teaching of the cognitive object. Thus, any likely disharmony could be considered by the learner as an additional burden rather than a thinking tool of confirmation or rejection of matters and drawing of conclusions.

In order to improve this situation certain researchers suggest the kind of teaching which uses multiple representations, the cross-correlation of which leads the student to the constitution of cognitive schemata / forms which can then be used in the analysis of examined phenomena and the resolution of relative problems.

From the examination of bibliography [2-5] it results in that particularly effective instructively representations of physical systems can be created with the use of ICT. Meanwhile, the use of suitable programming tools allows the simulation of phenomena and systems, the presentation of principles and laws of Physics, the collection and processing of data and measurements. It also allows individualized teaching and learning [6, 7] which is of importance in the Information Society.

The previous report justifies the efforts of reformation of teaching so that it acquires an interactive character that is ensured by the introduction and use of suitable instructive and learning environments via the ICT. In the present work certain efforts of reformation of teaching towards this direction will be commented. The first effort began with the use of courses that was created with the help of multimedia writing tools and was used in combination with the lectures in order to create a particular stimulus to the student. The second was based on the transformation of part of a laboratory so that the experimental data are collected, recorded, analyzed and processed via sensors that were connected to a PC [8]. In the third one, simulation programmes of laboratory experiments were used, which aimed to substitute part of laboratorial exercises leading, according to the researchers which introduce this method, to the more essential comprehension of taught ideas of Physics.

Each one of the previous approaches presents advantages as well as disadvantages. The use of multimedia applications in teaching is impressive and it can even include simulations of experiments and laboratory exercises compensating to a certain degree the lack of a real laboratory. However, the student feels that he uses a program where according to Varley [9, p 6] :

> "…… The software resembles a mysterious box in which the operations of program and unluckily physics are hidden. …… But the software provides a simulation of the experiment and it is

> not the actual apparatus thus the student could feel that the simulation is nothing but a game which has a somewhat tangential connection with the laws of nature …… ".

Which type of specialized software improves the situation offering simulations that are also compatible with those of an inquiring process and also put forward the instructive objectives that have been placed? How can a student be led to simulations that are educationally active giving the sense that it is also the behavior of the simulated physical system which is being tried?

In the present work the possibility that a mathematical package of general purpose, MATHEMATICA®, can be used by the students in the modeling and studying of oscillators with the help of a computer is presented. The package was selected for its advantages some of which are [10-13]:

- the particularly easy way of writing of mathematical symbols and relations.
- the simple way of creating any type of graph that depicts functions, curves and surfaces
- the creation of animations that present the motion of systems in the usual space and the space of phases.
- the possibility of the program "to resolve" almost each mathematical problem for which a known method of calculation (analytical solution or numerical approach) exists.

For each one of the oscillators (harmonic, with damping, forced) the students practiced themselves experimentally with the help of a suitable experimental setup so that they have been introduced to the laboratory stimulus. Then the team that was practiced experimentally was separated randomly in two. The one of the two smaller teams was practiced more in an accordingly prepared by the researchers' computer lab. In this laboratory and for the physical systems that were selected, the students were practised using programs that, either were created at the phase of preparation with the help of MATHEMATICA®, or were collected by its particularly rich bibliography [9, 14-16]. It must be noted that for this exercise they had already been taught for six hours the basic operation of the program as well as the principles of animation.

The students were supposed to use their background knowledge of physics for the specific physical systems, to write the model that corresponds to the oscillator, to create with the help of program tables of measurements, graphic representations and diagrams on different values of parameters of the model, but also to create, where that was possible, an animation of their relative motions. Finally they had to create their own programs - models and study them with the help of MATHEMATICA®.

The present study was performed on a sample of 152 of students (118 female and 34 male) of the first and second year in the Pedagogical Department and 124 (12 female and 112 male) students of the first year of the Polytechnic Department. The investigation was performed during a whole semester and the student participation was on a voluntary basis. All students participating in the present research had already followed a semester course on the use of ICT. One limitation which on the same time is an advantage of the present study is that the students have different scientific background (Pedagogical vs. Engineering).

In the following paragraphs the reasoning of certain of these programs in the final form that was employed for the exercise of students is presented. The pleasant surprise of the work of the researchers was that after the end of the obligatory laboratory exercise the students continued to write programs that do not fall any short to those of the existing bibliography [9]. The educational characteristics of the students' work are discussed in the next section.

II. THE LINEAR OSCILLATORS

An oscillator [17, 18] is usually modeled by a specific body of mass m tied up to the end of a spring constant k, the other end of which is steadfastly connected to a point. Let's assume that F(x) is the force of spring on the body of mass m and x =0 is the equilibrium position of a system where F(0)=0. The use of the second Law of Newton gives the following precise differential equation of movement:

$$m\frac{d^2x}{dt^2} = -F(x) \qquad (1)$$

A. The harmonic oscillator

1) The physics of problem

Considering small shifts, round the equilibrium position, in the bibliography F(x) is usually approached with the two first terms of Taylor Series round the point x=0 resulting:

$$F(x) = F(0) + x\frac{dF}{dx}(0) \qquad (2)$$

Placing $\frac{dF}{dx}(0) = k$ the force becomes $F(x) = kx$ and results the linearized equation of motion

$$\frac{d^2x}{dt^2} + \omega^2 x = 0 \quad \text{where} \quad \omega^2 = \frac{k}{m} \qquad (3)$$

The solution of last equation is of the form:

$$x = A\cos\omega t + B\sin\omega t \qquad (4)$$

This equation can also have the following form

$$x(t) = C\cos(\omega t - D) \qquad (5)$$

where $C = \left(A^2 + B^2\right)^{1/2}$, and ω is angular frequency of oscillation.

MATHEMATICA® will be used in order to resolve the equation (13) numerically and perform a simulation of the motion of the particle of mass m.

2) Study with MATHEMATICA®

Here with a discrete model of oscillator is employed with a minimal code [9, p 85] that is easily recognizable by the student

```
m = 4.;
k = 20.;
ti = 0.;
tf = 10.;
dt = 0.1;
x[ti] = 0.1;
v[ti] = 0.;
Do[ F[t] = -k * x[t];
        v[t + dt] = v[t] + (F[t] / m) * dt;
        x[t + dt] = x[t] + v[t + dt] * dt,
               {t, ti, tf, dt}]
data1 = Table[{t, x[t]}, {t, ti, tf, dt}];
plot1 = ListPlot[data1, AxesLabel → {"t", "x[t]"},
   PlotJoined → True]
```

Initially the constants m and k are declared and the initial and final value of time t_i and t_f as well as the time step dt. They are then given the initial position and speed and the process of calculation of values of position and speed for each one of the determined time moments. The command "Table" prepares a table of values while the data1 gives the data on output via the ListPlot of the graphic representation of position vs time. The implementation of the program gives the graphic representation of position vs time (Fig. 1).

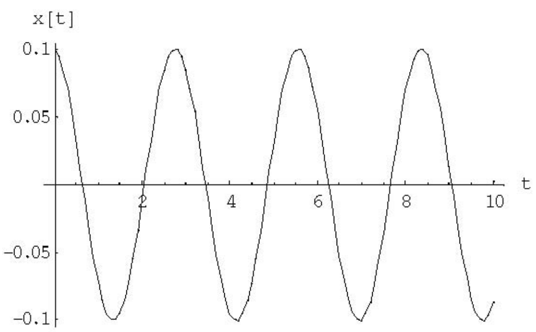

Figure 1. Position versus time for the harmonic oscillator.

The next section of the code is used for the successive snapshots via which the motion of the harmonically oscillating particle will be represented. In this section of the program the suitable system of axes, their range of values (SetOptions), the size of point which portrays the particle that is moving are selected and finally the snapshots of motion (Do) are materialized. In Fig.2 a snapshot of the motion of the oscillator appears.

```
ti = 0.0;
tf = 20.0;
dt = 0.1;
x[ti] = 0.0;
Do[x[t] = Cos[t + 1], {t, ti, tf, dt}];
SetOptions[Graphics,
    AspectRatio → 1,
       Axes → Automatic,
          PlotRange → {{-1, 1}, {0, 0}}];
Do[Show[Graphics[{PointSize[0.05],
    Point[{x[t], 0}]}]],
     {t, ti, tf, dt}]
```

Selecting with the mouse all the snapshots and from the menu of the program initially Cell and then Animate Selected Graphics in the cell from the choice began, the particle appears to erase its orbit. Moreover, a menu is presented, with the help of which the inversion of movement from the last one to the initial snapshot (time inversion) is possible but also the "freeze of motion" as well as the possibility of movement from point to point of the orbit in front or behind the time.

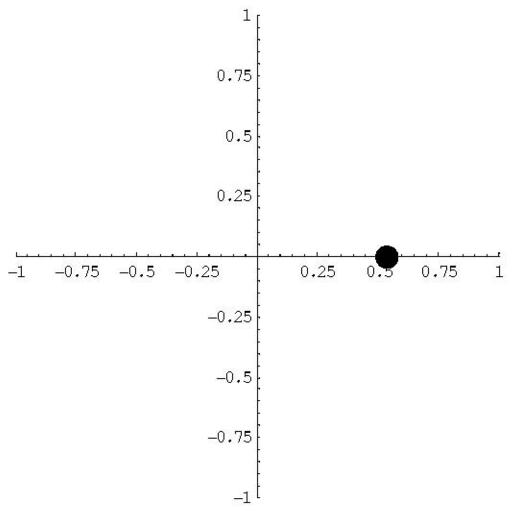

Figure 2. A snapshot from the animation of the harmonic oscillator.

B. *The oscillator with damping*

1) *The physics of the problem*

Let's consider that mass m, besides the force of spring, also accepts a type of friction which is proportional of speed. The total force has now the form

$$F(x) = -kx - b\dot{x} \qquad (6)$$

where b is one positive constant. As in the previous case, small shifts from equilibrium are supposed and placing $\omega^2 = k/m$ and $\lambda = b/m$ the following equation is obtained:

$$\ddot{x} + \lambda\dot{x} + \omega^2 x = 0 \qquad (7)$$

The solution of this equation under the condition that the damping is not particularly big has the form:

$$x = ce^{-\lambda t/2} \cos\left\{\left(\omega^2 - \tfrac{1}{4}k^2\right)^{1/2} t - d\right\} \qquad (8)$$

There are two interesting characteristics of motion:

1. The reduction of width of the oscillation with time as this is determined by the exponential part. The bigger the value of constant λ, the faster the reduction is.
2. The reduction of angular frequency of oscillation which in this case it becomes

$$\omega_1 = \left(\omega^2 - \tfrac{1}{4}\lambda^2\right)^{1/2}$$

2) The study with MATHEMATICA®,

The program that follows handles the discrete model of the oscillator with damping (by a modification of the corresponding program in [9]) and as a result it gives values of time, position and speed, via the command Print, as well as the graphic representation of position vs time

```
m = 1.;
k = 1.;
b = 0.1;
ti = 0.;
tf = 70.;
dt = 0.2;
x[ti] = 1.;
v[ti] = 0.;
Do[ Print[{t, x[t], v[t]}];
  F[t] = -k * x[t] - b * v[t];
   v[t + dt] = v[t] + (F[t] / m) * dt;
   x[t + dt] = x[t] + v[t + dt] * dt,
         {t, ti, tf, dt}];
data1 = Table[{t, x[t]}, {t, ti, tf, dt}];
ListPlot[data1, AxesLabel → {"t", "x[t]"},
                      PlotJoined → True]
data2 = Table[{t, v[t]}, {t, ti, tf, dt}];
ListPlot[data2, AxesLabel → {"t", "v[t]"},
                         PlotJoined → True]
```

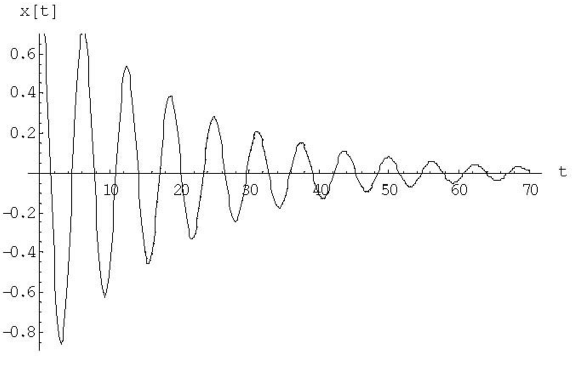

Figure 3. Position versus time for the oscillator with damping..

The next section of code is used for the successive snapshots via which the motion of the oscillator with damping will be represented

```
ti = 0.0;
tf = 6.0;
dt = 0.1;
x[ti] = 0.0;
Do[x[t] = Exp[-t] * 2 * Cos[4 t - 1], {t, ti, tf, dt}];
SetOptions[Graphics,
    AspectRatio → 1,
      Axes → Automatic,
        PlotRange → {{-2, 2}, {0, 5}}];
Do[Show[Graphics[{PointSize[0.05],
    Point[{x[t], 0}]}]],
     {t, ti, tf, dt}]
```

C. The forced oscillator

1) The physics of the problem

In the case that is examined, besides the force of spring, mass m also accepts a forcing force of the form of $F_0 \cos\Omega t$, so that the total force is given by the expression

$$F(x) = -kx - F_0 \cos\Omega t \qquad (9)$$

If damping does not exist and the mass executes small movements round the equilibrium position, the equation of motion takes the form

$$\ddot{x} + \omega^2 x - \mu\cos\Omega t = 0 \qquad (10)$$

where $\mu = F_0/m$.

There seems to be a particular interest in the case of solutions of (10), where Ω=ω, that is to say, the frequency of forcing force becomes equal with the eigen-frequency of the oscillator when resonance occurs. In this case the solutions are of the form

$$x = \frac{k}{2\omega}\sin\omega t \qquad (11)$$

which also satisfies the initial conditions x=0, b=0 at t=0.

2) Study with MATHEMATICA®,

The program that follows handles the discrete model of the oscillator with forcing (by a modification of the corresponding program in [9])

```
m = 1.;
k = 1.;
fo = 1.0;
u = 1.0;
ti = 0.;
tf = 35.;
dt = 0.2;
x[ti] = 0.;
v[ti] = 0.;
Do[ F[t] = -k * x[t] + fo * Cos[u * t];
      v[t + dt] = v[t] + (F[t] / m) * dt;
      x[t + dt] = x[t] + v[t + dt] * dt,
           {t, ti, tf, dt}]
data1 = Table[{t, x[t]}, {t, ti, tf, dt}];
plot1 = ListPlot[data1, AxesLabel -> {"t", "x[t]"}]
```

and as a result it also gives the graphic representation of position vs time

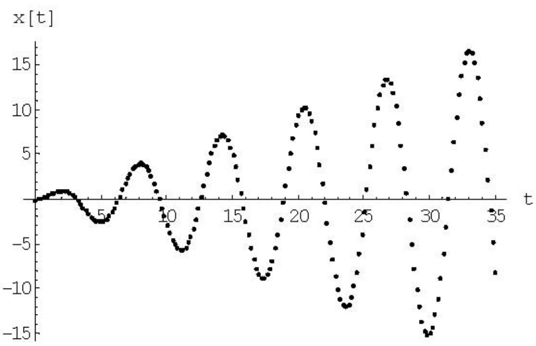

Figure 4. Position versus time for the forced harmonic oscillator.

The next section of the code is used for the successive snapshots via which the motion of the harmonically forced oscillator will be represented.

```
ti = 0.0;
tf = 20.0;
dt = 0.1;
x[ti] = 0.0;
Do[x[t] = t * Sin[t] , {t, ti, tf, dt}] ;
SetOptions[Graphics,
    AspectRatio -> 1,
      Axes -> Automatic,
        PlotRange -> {{-20, 20}, {0, 0}}] ;
Do[Show[Graphics[{PointSize[0.05],
    Point[{x[t], 0}]}]],
    {t, ti, tf, dt}]
```

III. CONCLUSIONS

The students participate in the present research voluntarily. The teaching of essential notions of MATHEMATICA® required a time of six hours during which they were taught basic commands of the program, graphic representations and the principles of animation.

The use of the first program required particular effort in order for the students to comprehend the way the values of functions are successfully calculated via the command Do.

Their initial effort to comprehend and later to create a program was limited by the fact that they considered as "program" the command of calculation of values, of functions, of position and speed and they tried to print results without taking into consideration the existence of initial conditions. Therefore, until they were convinced for the need to include them, most of the time, they were surprised with the "weakness of their PC" to comprehend their program.

They finally realized that a systematic way to comprehend and write the program is needed, that has the form,

Initial data $\rightarrow$ calculations $\rightarrow$ presentation of results,

so after the successful implementation of the first of them, they were trying to imitate it and improve, keeping its initial structure constant.

The idea of the existence of an original program would work equally well in most cases and irrelevantly to the form of motion they would face, it was a permanent thought.

With regard to the graphic representations or the creation of snapshots of movement they followed the directions precisely and since the program "had been running" without problems they were recording it, they tried various other choices, altering the values of the initial conditions.

However, in the final writing of the program none of the relative experimentations was included. The main opinion of students was that they wished their programs to resemble those of the bibliography (reasons of safety), while the research team realized that certain choices at the phase of experimentation were a result of random order rather than essential comprehension.

Their initial idea before the teaching was that for the creation of the animation motion even a picture - snapshot would be enough. In order for this situation to be improved one needs use techniques for the creation of animation from simple sketches using traditional ways. The teams materialized the models and simulated the relative motions.

They were then prompted to try altering parameters and initial conditions, watching the changes that result in the graphic representations and the depiction of motion. They were enthusiastic about the simulation of motion and particularly its possibility to go forward and backwards in time of motion that the program provides, realizing indirectly the inalterable form of the orbit relative to the time inversion.

This situation stepped aside the difficulty of the initial creation, created enthusiasm and showed the possibility of use of such processes in the creation and study of representations and models of physical systems.

The examples that were used and the programs that were created basically aim to prompt the student, or the professor to use the material that was created immediately in their daily study or teaching. The examples were selected so that simple numerical calculating techniques, that lead to graphic and numerical results, are used directly on the condition, the basic idea, that comes from physics and is hidden behind the numerical solution of a problem, is comprehensible to them [19, 20].

The opinion of researchers is that the structure of programs makes the student to feel that similarly elementary programs could be generalized, even if they are created with the calculators of the Physics laboratory [9]. Their simplicity encourages thoughts that lead to affairs and experimentations since it is easy to formulate questions like [9]:

"……what would happen if we altered ……."

making the student capable to discover forms and produce results with techniques that are similar to those of the experimental work in Physics.

As an example of experimentation the possibility of modification of programs with change of numerical values of all initial physical quantities that results in motions quantitatively different but qualitatively similar is reported.

It seems that the use of software and computers generally contributes to the growth of multiple representations in Physics, the creation of simulations and models allowing an interactive type of teaching.

Concluding, it appears that with the help of computers a student can approach cognitive regions with difficult mathematic formalism, like realistic problems that students daily come across, producing precise as well as approximate solutions of desirable precision, decreasing the dissemination of matter in the analytic programs and restoring its unity. An investigation of learning situations that have been located as instructive obstacles for the students and this it is a very important result in which will be reported in future work.

Moreover, the use of mathematical package can be a powerful tool in the hands of a professor in his/her effort to complete with success instructive work in a laboratory.

Finally, an instructive suggestion for an active, dynamic and multiform introduction of a computer and corresponding mathematic software for the modern teaching of Physics in the class-laboratory is proposed. This proposal has to do with the implementation of a series of group work available for the colleagues that have their possibility of adaptation depending on the level of teaching.

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Manuscript received 30 November 2007. Published as submitted by the authors