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Contemporary Physics Teaching using Mathematica Software

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Abstract:

This paper describes innovative uses of the Mathematica software in Physics teaching. It provides an overview of the Mathematica functionality that makes it easy for educators to integrate the software into pre-college, college and higher education classrooms. Mathematica offers an interactive classroom experience that helps students explore and grasp concepts and gives teachers the tools they need to easily create supporting course materials, presentations and assignments. Mathematica can easily generate visualizations in the learning of scientific phenomena and processes. It can create or recreate a phenomenon or environment corresponding to a physical process through simulation modeling and can thus provide a powerful instructional tool for addressing conceptual and procedural learning difficulties. In this manuscript we have demonstrated equation solving and plotting through the use of the Mathematica software. Also, we have focused on providing some examples of simulation related problems such as the oscillating pendulum. Furthermore, we have also portrayed some of the uses of Mathematica solutions in a few branches of Physics. The highly interactive and user friendly interface of this software can perhaps display widespread applications in all branches of teaching and research.

Keywords: *Interface notebook, educators, computer simulations, equation solving, graphics.*

PACS: *01.40.Fk, 01.50.H-, 01.40.gb, 01.50.Zv, 02.70.-c.*

1.Introduction

For more than 20 years, educators, academicians and scientists around the globe have utilized Mathematica as an indispensible tool for everything from teaching naïve concepts in the classroom to giving world class presentation and for pursuing momentous research using some of the world's largest constellations. Mathematica is a world renowned, fully integrated system software for technical computing and it provides an interactive front end with notebook interface. Its capabilities such as symbolic manipulation, special functions, graphics, typesetting and extensibility enable educators to mould this software into a teaching tool. It basically provides a platform for doing Mathematics on the computer and thus finds a widespread applicability in Physics teaching (J.H.VanDrielet a.2001). This enables the teacher to focus on Physics concepts rather than going through algebraic or mathematical steps which the student already knows, but can take quite a bit.

Mathematica for students has all the flexibility and adaptability of Mathematica but at a fraction of cost. Mathematica can revolutionize Physics teaching, especially in India as for less than the price of a textbook, a student can utilize the same technology on a personal computer as used by the engineers, economist, scientists, mathematicians and educators worldwide.

Mathematica characterizes the world's largest assembly of algorithms, visualization techniques and high performance computing capabilities to handle large datasets, facilitating educators who are especially involved in academic research (P. Cobb.2003). The most exclusive feature of Mathematica which makes it stand apart from other computing softwares is the fact that it allows the user to compute the way in which one thinks. Through its free form linguistic input, the user can enter instructions in plain English, without any knowledge of the syntax. It provides immediate results and its free form query option helps in accessing a wide range of Mathematica functions and terabytes of Wolframs's knowledge for use in computations (www.wolfram.com.2011). Thereby, Mathematica projects out to be the ideal software for aiding physics education.

2.Role Of Mathematica Software In Physics Education

Mathematica offers an inclusive atmosphere to create materials for various physics courses, flawlessly combine a powerful calculation and dynamic visualization engine with proficient documentation. Within the Mathematica notebook, the teacher can cultivate solutions to multifarious problems that amalgamate symbolic derivatives, numerical calculations and graphical displays in an interactive document. Thus, Mathematica enables the educator to concentrate more on the conceptual development and visualizations than on the particulars of the algebra or procedural programming. The results can be documented and presented in a very attractive format using the typesetting tools provided by the front end interface.

With Mathematica for Physics educators, everything can be interactive and the users can create their own models with complete intuitive controls which can easily alter values with single command. Mathematica's inclusive and adaptable features allow schools, colleges and universities to streamline their software management and lower technology expenses by replacing other softwares with Mathematica. Also, Physics students can utilize Mathematica to master concepts, complete homework assignments and make projects, that too without any need to buy specialized software for each task.

During designing or revising a course, Mathematica enables the teacher to organize and test ideas and immediately develop them into actual lesson plan. Mathematica for physics educators and students is a great investment since it grows with the user throughout their academic as well as professional career.

Teaching Quantum mechanics with Mathematica can resolve difficulty issues among students who often struggle in understanding this subject during the introductory stage. They find this subject to be both mathematically difficult and counterintuitive as it is very difficult to develop a quantum intuition for our universe in which h (Planks constant) is small. Mathematica can easily address these issues and can easily provide tools for both computation and visualization of related problems.

Calculus based introductory physics courses can easily be taught with Mathematica. It can also be used as a tool for analyzing experimental data. These experiments may include exploring of the diffraction patterns with a CCD cameras or using digital audio to measure Doppler shift.

The Wolfram Education group provides free online seminar catalogue which offers a series of seminars for learning as well as implementing Mathematica. It is a time savior as it allows the educators to utilize existing course materials and examples developed by other educators and refine them as per need. The catalogue offers a number of brief demonstrations of various simulations related to different physical problems involved in Physics teaching such as the visualizing the effect of three dimensional electric field, motion in a central field or the conservation of momentum in a Canoe.

3.Solution And Graph Depiction Of Equationswith Mathematica

Mathematica helps to explore formulas, solve equations and prove theorems. The user can analyze mathematical functions of complex numbers and datasets of almost unlimited size with a variety of statistics operations and probability distributions. Mathematica interface notebook allows handling linear and non-linear optimization problems, operate matrices, strings and data arrays and also solve integrals and differential equations. We can explore changes to text, functions, formulas, matrices, graphics, tables or data.

Mathematica's powerful graphics function helps in plotting single line graphs, scattering plots and elegant 3D models. Also, it is of special interest in physics teaching as it helps visualize mathematical functions and surfaces, scientific data and specialized objects, all with automated aesthetics. This tool of Mathematica is of particularly helpful in higher education in Physics as the datasets obtained from experiments can be visualized to discover underlying pattern even if the data is complex and is irregularly sampled. Using this tool, the students can generate 2D or 3D histograms, charts, contour and density plots and stream and vector fields.

To solve an equation in Mathematica, the command used is Solve and the applicable format is Solve[the equation written with a double equal sign, the variable to solve for]. For instance, when an object is dropped from rest to fall 100 under the action of gravity, the equation relating displacement and time of fall 't' is

$$d = \frac{1}{2}at^2 \qquad (1)$$

$$100 = \frac{1}{2}(9.8)t^2 \qquad (2)$$

The above work is the Physics, and evaluating't' is the Mathematics which can be done in the Mathematica notebook by using the Solve command. The input is displayed in a line called In[1] and the output appears in a line Out[1].

In[1]:= Solve$\left[100 == \frac{1}{2}(9.81)\,t^2, t\right]$

Out[1]= {{t → -4.51524}, {t → 4.51524}}

By using the command Plot, we can display the variation of displacement with time when the object falls under the influence of gravity. We can define our own time interval (say that the time taken by the object to fall from a certain height is 10 seconds) and can then plot a figure between displacement and time interval. One way to performing this task on Mathematica is to first define the function in terms of the variable (here t is the variable). An underscore is placed after the variable name. The Plot command is used in the next input line using the following format: Plot[name of the function to plot, domain of the plot]

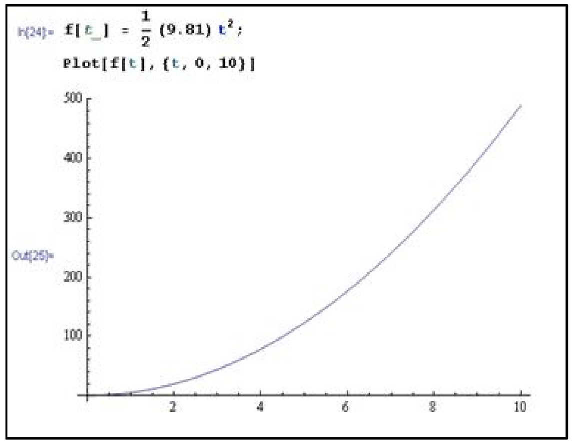

Figure 1: Graph displaying the variation of displacement (y-axis) with time (x-axis)

Now, we have the graph (Figure 1) and can switch to the Physics involved. We can question whether the object falls the same distance during each one second or whether the velocity changes by the same amount during each one second interval? Also, we are aware that velocity is a derivative of displacement, so the graphical representation is shown in Figure 2. This is a simple example and the plot is 2D.

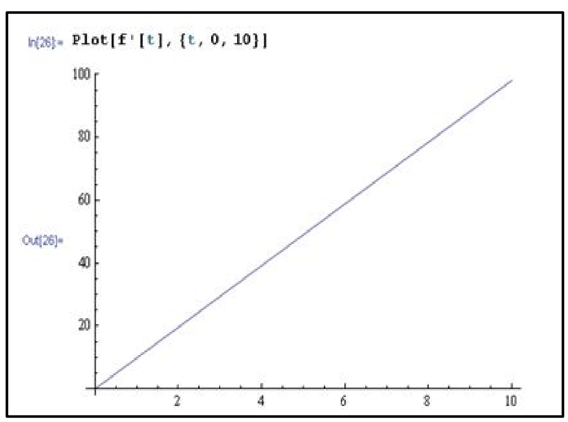

Figure 2 : Graph displaying the variation of velocity with displacement.

However, when we have two variables, we can switch over to 3D plots. Figure 3 shows a 3D plot which is related to our research work in Quantum Chromodynamics. We have shown the variation pattern between the physical string tension among quarks, the spatial string tension and temperature (N.Hothi etal.2010). The string tension and temperature are the two variables and the spatial string tension is evaluated through Mathematica and is plotted simultaneously. Thus, using Mathematica, we can solve an equation and instantaneously plot 2D or 3D plots, which find a wide applicability especially in experimental Physics education.

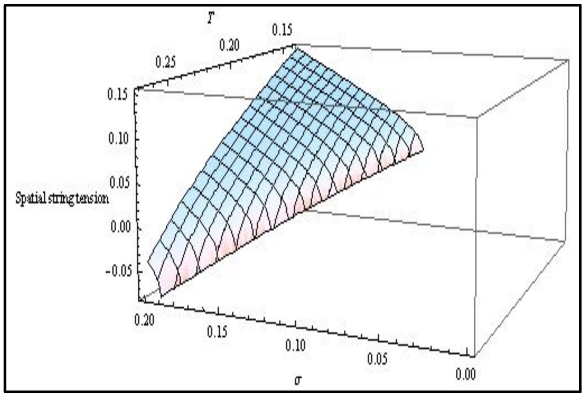

Figure 3: Plot displaying the variation of spatial string tension with temperature and physical string tension

4. Mathematica Solutions For Various Branches Of Physics

Mathematica Software provides an infinite range of solutions for almost all branches of Physics. In this particular section, we have explicitly depicted a few examples where Mathematica Solutions could be deployed (www.wolfram.com.2012).

4.1.Optics

With the aid of Mathematica, one can augment systems of symbolically defined lenses and mirrors of different focal lengths, test optical components with built-in image processing or data analysis functions, and compute complex ray-tracing models. The Mathematica solutions can easily integrate these proficiencies with built-in special functions, advanced differential equation solvers, and the most automated and reliable computation, development and modulations to the organized environment available for a particular situation.

4.2.Material Science

Material Science is one of the most enduring and popular Physics research field in modern times. Mathematica can help to model new materials using potent emblematic and numeric computational abilities. It can visualize crystal structures interactively and also compute the performance by scrutinizing deformation and failure data with sophisticated statistics. All this can be easily done in one amalgamated workflow. The Mathematica Materials Science solution is the most mechanized and dependable computation, development and deployment setting available in these days.

4.3.Astronomy

Mathematica is very useful in computing positions of astronomical objects in real time, building models, analyzing data, and rapidly generating collaborating conceptions visualizations in a simultaneous and integrated pattern. The Mathematica Astronomy solution syndicates the most cultured data analysis proficiencies, world-class image processing and exceedingly augmented differential equation solving with an in built analogous computing and 64-bit technology.

4.4.Statistics

Statistical analysis of data is required in almost all branches of Physics research and teaching. Mathematica helps to pull in the data into theirs, do standardized or custom analysis and visualization, then spawn and install interactive reports all in one system and that too simultaneously. The Wolfram statistics solution includes potent optimization and statistics functionality in conjugation with exclusive competencies like accessible dialectal input, instant interactivity, and the dependability.

5.Generation Of Simulation By Mathematica

Computer simulations are basically computer generated dynamic models which present theoretical or simplified model of various real world physical phenomena or processes. They may incorporate animations, interactive laboratory experiences as well as visualizations. Computer generated simulation can be of extensive use in Physics teaching. Using Mathematica, we can create simulations to investigate physical phenomena that cannot be completely explored with traditional means. Hypothesis related to several Physics problems can be easily tested by creating simulations. We, have demonstrated a simple simulation of the motion of an oscillating pendulum (J.R.Brannanetal. 2010) using Mathematica. The complete details of generating this simulation (coding) have been excluded from this manuscript as it would require a lot of space. However, the brief demonstration of the example is as follows:

The equation of an oscillating pendulum is

$$\frac{d^2\theta}{dt^2} + \frac{g}{L} sin\theta = 0 \qquad (3)$$

and θ is the angle is the angle of the pendulum at time t. The above equation can be solved by usingthe command NDSolve in the Mathematica notebook. Snapshot of the simulation is shown in Figure 4 . With the help of the sliding control buttons we can fix the value of the angle θ and the corresponding mass and length of the pendulum. On releasing the system with the Play button, we can view the simulation as to how the pendulum swings displacing from one position to the other with changing time. The small window in the right displays the variation pattern between the displacement and the time and the small blue dot here changes position with motion.

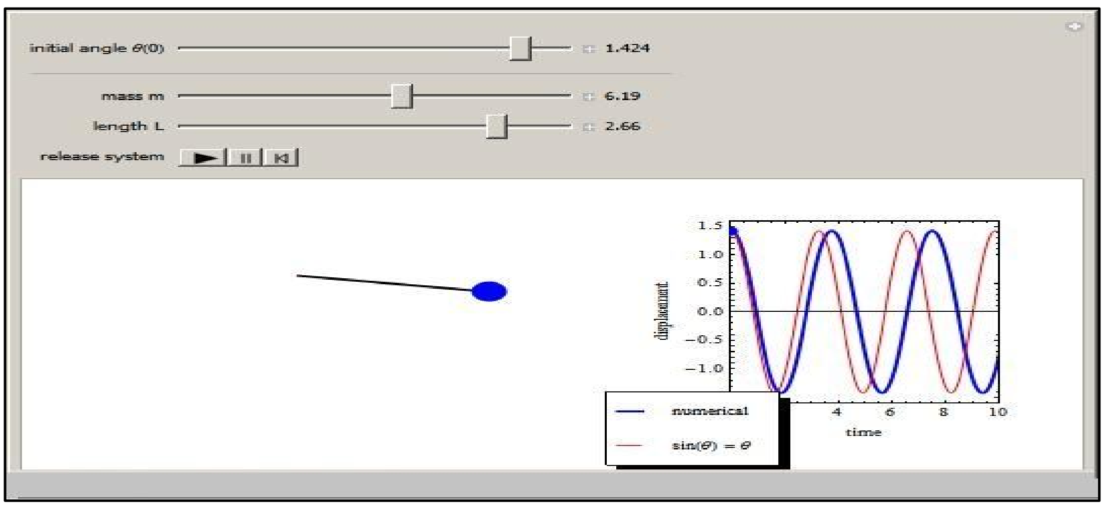

Figure 4: Snapshot of the simulation of the motion of an oscillating pendulum using Mathematica

6.Conclusion

The present contribution portrays some of the most proficient features of Mathematica software that can be evidently used in Physics teaching. The highly scientific and problem solving feature of this software efficiently enables the teachers to inculcate this modern day utility in teaching at School, College and University level. We have outlined some pedagogical ideas that could drive the use of this computing software in the classroom to make a significant impact on physics learning and creating cognitive links between the world of mathematics and that of physics.

7.Reference

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