

Animated Spreadsheets as a Teaching Resource on the Freshman Level

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Abstract

Computer animation can serve as a powerful teaching tool. Too often, however, interactive computer animation degenerates into a video game, with students blithely entering data and enjoying "gee-whiz" graphics while managing to ignore completely the underlying physics and math - the understanding of which is the actual intent of the animation! Such unfocused trial-and-error engagement can be largely avoided if the animation is introduced as a tool rather than as a "black box." Spreadsheets lend themselves very well to this. One simple, easily-understood macro to "step" time is all that is required. Graphs based on formulas referencing this time immediately become animated. If the student has entered and understood the spreadsheet formulas in the first place, the animation is a completely natural extension of a familiar tool. The visual impact is just as great as with more sophisticated animation but is a natural outgrowth of the underlying physics and math rather than being simply the output of a "black box."

Introduction

It is increasingly common for university students to have classroom access to computers. Science and engineering students are invariably introduced to computers early on and, as part of their early training, generally work with spreadsheets. In the ASU Freshman Integrated Program for Engineers (FIPE), for example, students are introduced to computers on their first day and receive a thorough grounding in spreadsheet basics during the following weeks. In the course of projects, labs, and homework they become quite adept at entering data and formulas into a spreadsheet then graphing, analyzing, and understanding the results. The spreadsheet becomes simply a tool to them - fast, powerful, "high tech" but nonetheless just a tool.

Once this level of mastery and understanding has been attained there is potential for great fun and enhanced learning by adding animation to a spreadsheet. One simple macro is all that is needed to generate "computer movies" which aid tremendously in exploring complicated time-dependent phenomena. Provided it is the students themselves who actually create the

spreadsheets and provided they do indeed understand the physics and math thereof, the "black box" aura is avoided. Students are fascinated by the animation and invariably take a copy of the macro program home with them. Yet they recognize that it is nothing more than a simple extension of familiar spreadsheet techniques. They therefore treat the animation not as a video game but as a serious tool, albeit an enjoyable one to use. The result is effective learning based on solid conceptual underpinnings, mingled with a lot of "high-tech" fun.

Animation Macro

To animate a spreadsheet, all explicit time references on the sheet are written as absolute references to one single cell. A simple macro which increments the contents of this cell will therefore step the entire spreadsheet forward in time. Such a macro is given below, taken directly from an Excel 5.0a spreadsheet.

```
' Spreadsheet Animation Macro
' Macro recorded 5/17/95 by R. B. Doak
Sub Step_Time()
' Row and column of time cell:
row_t = 5
col_t = 2
' Number of time steps:
n_points = 50
' Read current value stored in time cell:
t = Cells(row_t, col_t).Value
' Prompt for desired time step:
delta_t = InputBox("Enter time step (s)", _
    "WAVE MOTION", 0.1)
For i = 1 To n_points
' Increment time
t = t + delta_t
' Place incremented value in time cell
Cells(row_t, col_t).Select
ActiveCell.FormulaR1C1 = t
Next
End Sub
```

²³ Supported by the National Science Foundation under Cooperative Agreement EEC92-21460

The macro assigns the coordinates of the single cell containing the value of time (row #5, column #2 in this example), sets the number of time steps to be taken by the macro (50), retrieves the current time, prompts the user for the desired time increment per step, then steps forward in time from that value (or backward, if the time increment is negative). The macro can be terminated at any time by hitting the ESC key then clicking on "End" in the "Macro Error" box which appears. There is no sophisticated programming involved here, which is intentional. Students can and do understand how the macro works and are able to change parameters as desired. Reading and understanding Visual Basic macros is much easier than writing them, but students interested in further information can consult "Macros, writing" on the Excel "Help" menu. The animation macro is best stored on a worksheet within the workbook of interest. It is accessed from the "Macro" command on the "Tools" pull down menu. It could easily be assigned its own button on the "Tools" menu if desired.

Using the Animation

Two examples will illustrate the utility of the spreadsheet animation. The first example is that of a simple non-periodic traveling wave. Freshman students generally have no difficulty in understanding the concepts of amplitude and velocity of a traveling wave. They are mystified, however, by the functional dependence $F(x, vt)$ of a traveling wave (x , v , and t are all positive numbers). Even good students have difficulty understanding why the + sign corresponds to a wave

moving to the left and the - sign to a wave moving to the right. Eventually they comprehend that a constant value of x/vt corresponds to a fixed point on the wave pattern (e.g., a wave crest). To keep x/vt constant as t increases, x must decrease or increase, respectively, depending on whether the operator is + or -, moving the fixed point to the left or right, respectively, and corresponding to a leftward or rightward motion. This sounds trivial, but for first year physics students it is not.

As part of this learning process, it is useful to actually display the motion of a wave with the functional dependence $F(x, vt)$. Seeing is believing and the spreadsheet animation can provide the seeing. Again, however, the key point for reinforcing learning is that the students create the spreadsheets themselves and understand exactly how, what, and why the spreadsheet is calculating before the animation is added. For a class well-versed in spreadsheet techniques it is a matter of a few minutes to build the spreadsheet, enter the equations, and graph the calculations. Students must be directed to enter all time dependencies as absolute references to a single cell (row #5, column #2 in the below example) to facilitate the later introduction of animation. As they explore the spreadsheet by varying parameters, students reinforce their understanding of amplitude and velocity of the wave pulse. As they change the time and watch the wave pulse move, they perform exactly the same operation that the animation macro will automate. The transition to the automation is therefore completely transparent. Once students are comfortable with the spreadsheet, the animation macro is downloaded from

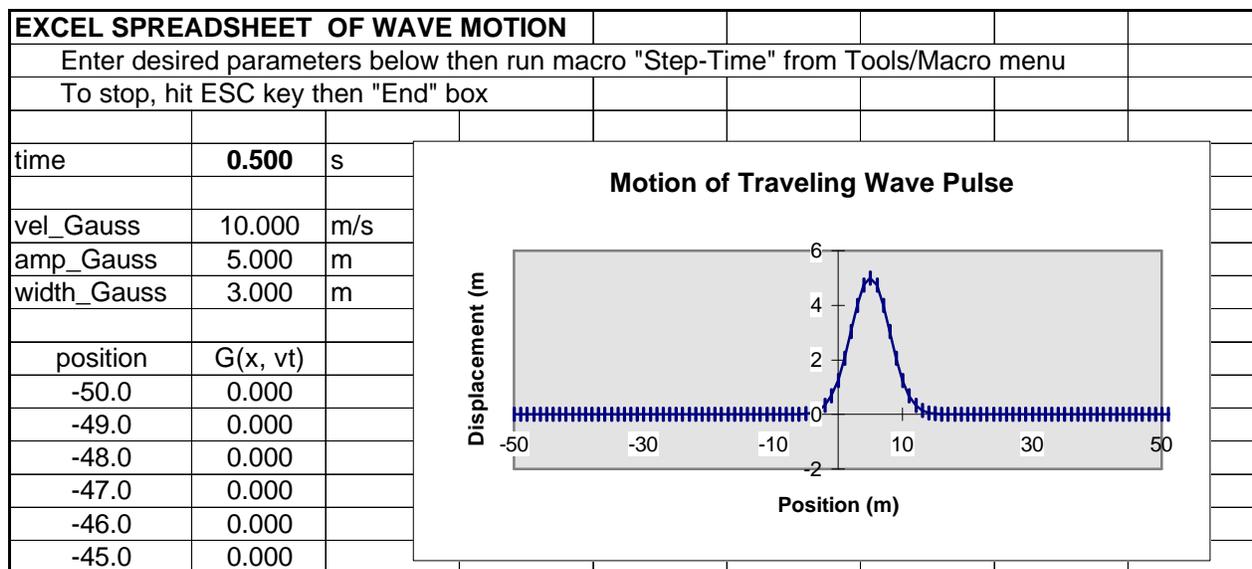


Fig. 1 - Example of Animated Spreadsheet for Non-Periodic Traveling Wave

a file server or passed around on a floppy disk. It is copied into the Excel workbook and run. By changing the +/- sign and observing the direction of travel, the students are forced to explore and understand the $x \pm vt$ functional dependence. The functional form of the wave used in the above example is a simple Gaussian, given by the spreadsheet formula in cell (row 12, col 2) and copied into the following cells of col 2

$$=B6*EXP(-0.5*((A10-B5*B3)/B7)^2)$$

or, algebraically,

$$F(x \pm vt) = A e^{-\frac{1}{2} \left(\frac{x \pm vt}{\sigma} \right)^2}$$

a pulse having amplitude A and peak width σ .

Understanding of the $F(x \pm vt)$ wave motion can be deepened by posing questions such as "What would happen if I ran time backwards?" or "What would happen if I the velocity were negative instead of positive?" This can all actually be tried with the spreadsheet animation, but before doing so the students should be forced to grapple with the problem e.g., discussing as teams the answers to the above questions, thinking about the changes in the functional complex $x \pm vt$, and writing down detailed predictions. The animation then either confirms the correct thinking or forces a re-investigation to revise misconceptions.

Another conceptual hurdle for many students studying traveling waves is in understanding that the physical elements of the medium move only locally and do not *travel* with the wave. Only the displacement pattern of the wave actually travels. This can be demonstrated very nicely with spreadsheet animation simply by changing the color and/or symbol of one of the plotted points, e.g. that at $x = 0$ as in the above example. A series of spreadsheet images from an animation is shown to the right. The visual impact of actually watching the motion of the marked point as the wave passes is immense. It is far more effective as a teaching tool than are attempts by the instructor to describe the motion verbally. Again, the proper pedagogical technique is to have the students wrestle with the problem before they actual see it displayed in the animation, for example discussing in teams how they expect the marked point to move, sketching a predicted plot of its displacement as a function of time, then carrying out the animation to test the prediction.

The animation is easily extended to periodic waves. After entering a sinusoidal function in place of the Gaussian pulse, the students can explore the spatial

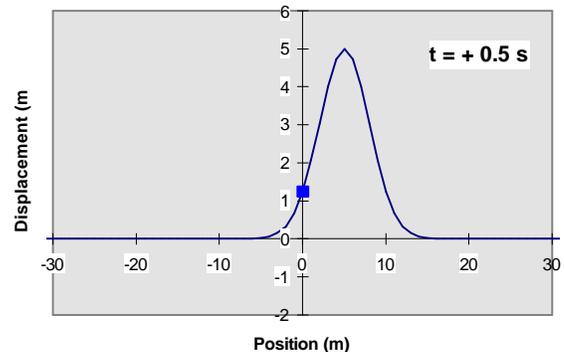
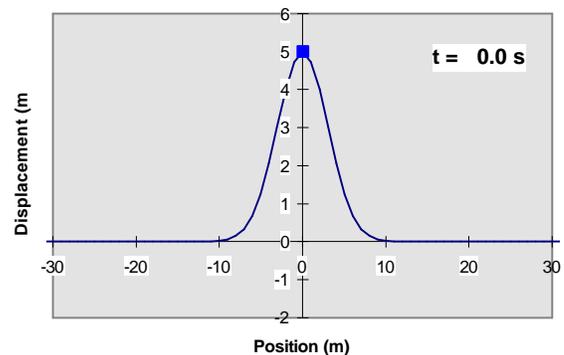
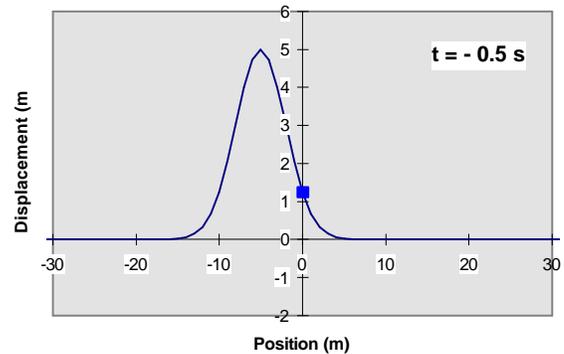


Fig. 2 - Motion of Marked Element

periodicity (wavelength) by varying parameters on a "static" spreadsheet. The discussion is then easily extended to temporal periodicity (period and frequency) by animating the spreadsheet. Once the basic concepts of periodic traveling waves are in hand, a second sinusoidal wave function can be entered onto the spreadsheet. Superposition can be tested by summing the two and then the whole range of interference phenomena can be explored. Standing waves and beat phenomena are beautifully demonstrated with spreadsheet animation.

A second obvious application of spreadsheet animation is in exploring projectile motion. This topic is reached fairly early in the introductory physics first semester and students might not yet be sufficiently skilled in spreadsheet techniques to make proper use of animation. If they are ready, however, animated clips can add a lot of fun and understanding. The equations of motion for a projectile comprise $x(t)$ and $y(t)$ coordinates parameterized with respect to time. Eliminating time gives the path $y(x)$ of the projectile, allowing the primary concepts to be presented with no explicit time dependence. Thus animation is not crucial to the understanding. Nonetheless, there is a certain visceral satisfaction to "see" the projectile actually flying through space. One example is given below, the classic "shoot

the monkey" problem of introductory physics. The scenario is as follows: The hunter aims directly at the monkey, and fires. But the monkey drops from the tree at exactly the instant the gun is fired. Will the bullet hit the monkey? (SPCA: Note that the bullet is traveling only 50 m/s, slow enough that the monkey will not be injured!) As you probably remember from Freshman physics, the bullet cannot miss. At any point in time the bullet has dropped a distance $\frac{1}{2}gt^2$ below a straight-line path from the rifle to the original position of the monkey - and that is exactly the same distance the monkey has dropped below his original position. So when the bullet reaches the x -coordinate of the monkey, it must be at the monkey's y -coordinate. It is fun to see it confirmed on an animated spreadsheet, however.

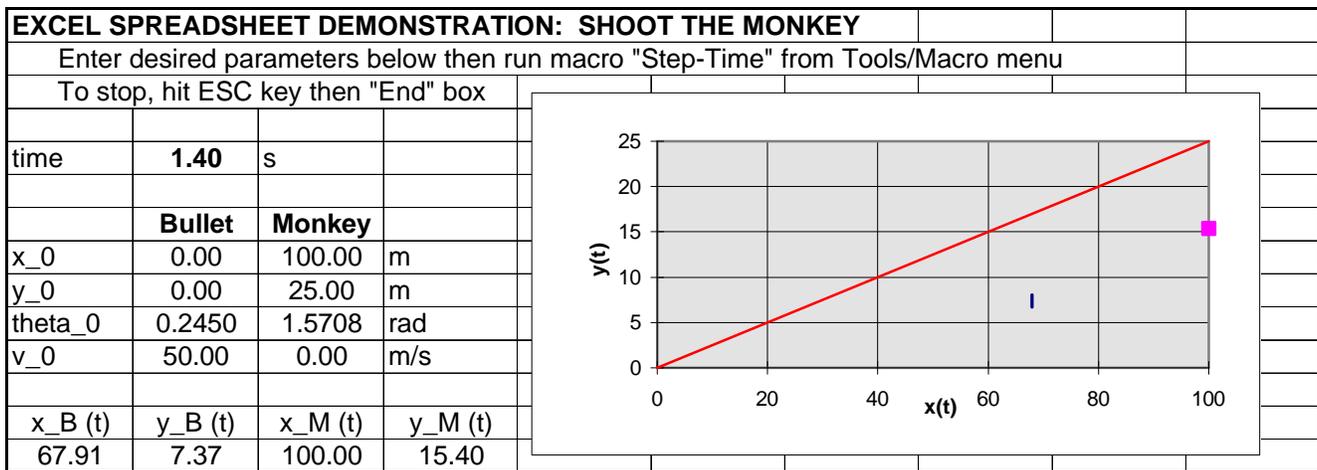


Fig. 3 - "Shoot the Monkey" Animated Spreadsheet

A straight line has been added to guide the eye from the rifle at (0 m, 0 m) to the initial position of the monkey at (100 m, 500 m). At the instant shown, the bullet (triangle) has covered about two-thirds of the distance to the monkey (square). Reading across the cells in row 14, the following equations have been entered:

col 1: $=\$B\$8+\$B\$11*\text{COS}(\$B\$10)*\$B\5
col 2: $=\$B\$9+\$B\$11*\text{SIN}(\$B\$10)*\$B\$5-9.8*\$B\$5^2/2$
col 3: $=\$C\$8+\$C\$11*\text{COS}(\$C\$10)*\$B\5
col 4: $=\$C\$9+\$C\$11*\text{SIN}(\$C\$10)*\$B\$5-9.8*\$B\$5^2/2$

which are easily recognized as the equations of motion under constant gravitational acceleration $g = 9.8 \text{ m/s}^2$. The macro is shown to the right. Given finite time steps, the trick is to set the tolerance for properly registering the "hit" for arbitrary incident velocity. The algorithm to the right seems to work reasonably well.

```

Sub Step_Time()
  ROW_time = 5
  COL_time = 2
  t = Cells(ROW_time, COL_time).Value
  delta_t = InputBox("Enter time step (s)", _
    "SHOOT THE MONKEY", 0.1)
  For i = 1 To 300
    Cells(ROW_time, COL_time).Select
    ActiveCell.FormulaR1C1 = t
    t = t + delta_t
    Distance = ((Cells(14, 1).Value - _
      Cells(14, 3).Value) ^ 2 + _
      (Cells(14, 2).Value - _
      Cells(14, 4).Value) ^ 2) ^ 0.5
    Hit = Cells(11, 2).Value * delta_t / 3
    If Distance < Hit Then Beep
    If Distance < Hit Then End
  Next
  Cells(ROW_time, COL_time).Value = t
End Sub

```

Links:

- [Animated Excel Spreadsheet Demonstrating Wave Motion](#)
- [Animated Excel Spreadsheet Demonstrating “Soot the Monkey”](#)