Physics Simulation with Excel Spreadsheet

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Article Info	Abstract
Keywords: *Spreadsheets;* *Projectile motion;* *decay;* *wave function;* *Terminal speed.*	this study present several examples of using Excel spreadsheets to study and simulate physical phenomena, namely projectile motion, falling motion in The air, The wave function of particles in a one-dimensional box, and nuclear radioactive decay. Spreadsheets are used to analyze the motion of projectiles with and without resistance, falling objects with different terminal velocities, graphs of wave functions and probabilities with different values of n, i.e. n=1 to n=4, and nuclear decay with different probability values of P. The use of excel spreadsheets has proven to be very useful in the physics learning process, namely the rapid response to changes in data and graphs, according to the values given.

1. INTRODUCTION

In learning physics, media availability is essential to explain natural phenomena related to physics. Visualization aids or computer simulations are learning media that can describe physical phenomena. In recent years, the teaching of Physics has changed, namely by using the internet and simulations. The internet has been used as the primary tool that can make students actively involved in the learning process in the classroom. Teaching physics can also be made more interesting and active can also be maintained with simulations. However, the main thing is the development of methods that can simplify and improve a learner's ability to understand and develop conceptual understanding. Simulations can be used to teach concepts in Physics (Toback, Mershin, & Novikova, 2004). Simulating physics concepts is an interactive and convenient method to gain deep insight into the problem and its results.

The simplest and widely used method for simulating different physics problems is based on a spreadsheet program. Spreadsheets have been widely used as tools for teaching and learning physics. There are two main aspects of using spreadsheets, namely computational power to solve physics problems of varying complexity and graphical tools to display the results of these calculations(González, 2018). Simulation is very much needed in teaching science subjects, especially physics. The use of simulation in teaching physics can partially replace the role and needs of the laboratory. In general, physics experiments can be easily carried out in simulations by developing a spreadsheet-based simulator contained in

MS-Excel. Spreadsheet simulation can improve students' conceptual understanding(Katoch, 2020).

The potential of excel spreadsheets in learning Physics is the ability to visualize, simulate, and animate phenomena in Physics with dynamic display of numbers and graphs. Simulation using spreadsheet media is very effective in helping students learn because the simulation displays a graphic painting that is formed and is the same as experimenting in a laboratory. The use of Excel spreadsheet media is very important in abstract physics learning. Using an Excel spreadsheet will produce simulations similar to actual experiments in the laboratory. This shows that Interactive learning media help abstract physic concepts because students can analyze physics phenomena. (Tombade, 2011).

Many reports in the literature have been devoted to the use of spreadsheets to solve and understand various problems in physics (Baker & Sugden, 2007; Oliveira & Napoles, 2010). Excel spreadsheets are simple and versatile free and computing tools. Excel spreadsheets are easy to learn and easy to get. Spreadsheets can be used in several fields such as education, business, and research. It is relatively easy to learn Excel than any other computer language. Apart from that, spreadsheets are also a practical tool for performing calculations in both Basic Physics and mechanics, Quantum Physics, and Electronics.

In many works of literature, spreadsheets are widely used to teach physics, including simulating the time evolution of the chain and plotting the radioactive populations of all species involved as a function of time. An Excel spreadsheet was used to illustrate Lissajous charts, Weibull distributions for wind speed, and damped harmonic oscillators(Uddin, Ahsanuddin, & Khan, 2017). Excel spreadsheets can also be used in teaching basic statistics(Warner & Judge, 2001).In addition, the Spreadsheet is also used to simulate the longitudinal vibration of the coupled oscillator using the fourth-order Runge-Kutta method and to study vertical motion under the influence of a gravitational field(Singh, Kaur, & Khun, 2019; Grigore & Barna, 2015).In other literature, spreadsheets can be used to teach electromagnetism by simulation(Squire, Barnett, Grant, & Higginbotham, 2004).

Physics is considered a complex subject. In physics learning, students tend to understand the material well through giving examples, videos, visualizations, and simulations. An excel spreadsheet can perform calculations and graphical representations and simulations. In this article, simulations of several physical phenomena are carried out, namely projectile motion, falling objects in the air, particle-wave functions, and the radioactive decay of nuclei.

2. METHODS

Projectile Motion

The input values for the initial parameters are acceleration due to gravity (g), time interval (dt), initial velocity (v_0), and constant b are 9.8 m/s^2, 0.025 s, 20 m/s, 45^0, and 0.05 m/s^2, respectively in cells B5:D5. To facilitate the process of writing formulas for calculations, rename the "Name Box" of each input parameter value successively with 'g'; 'dt'; 'v_initial'; 'start_angle' and 'b'. Then in cells F4:J4 input the amount of time, x-direction velocity, y-direction velocity, x-position, and y-position. In cell F5, set the time at a value of zero (0) to cell F119 and cells L5 to L119 with an interval of 0.025. In cells G5 to cell G119 input the following formula:

=v_initial*COS(RADIANS(Initial_angle)).

In cell H5, input the following formula as v_1y value:
$$=v\_start*SIN(RADIANS(Initial\_angle)).$$
In cell H6, input the following formula: =H5-g*dt and the iteration is v_ny=v_(n-1)y-gdt. In cell I5, setting the value to 0 (zero), and in cell I6, input the following formula: $x_2 = x_1 + v_{2x}dt$ or in excel form:
$$I6=I5+G6*dt$$
For the next cell, cells I7 to I119,
$$x_3 = x_2 + v_{3x}dt$$
and the iteration is
$$x_n = x_{n-1} + v_{nx}dt.$$
In cell J5, setting the initial position value to 0 (zero), for the next cell input the following formula: $y_2 = y_0 + v_{2y}dt$ and in excel form: J6=J5+H6*dt.

For the next cell, cells J7 to J119,
$$y_3 = y_2 + v_{3y}dt$$
$$\vdots$$
$$y_n = y_{n-1} + v_{ny}dt$$
Next, in cells J7 to J119, replace the formula with
$$J7=IF(J6>0;J6+H7*sec;NA())$$
Furthermore, the formula used for projectile motion with air resistance is as in table 1

Table 1. Description of excel formula for projectile motion simulation

Cells	Formulas in Excel	
L5 – L119	Input time value starts from 0 to 2.85 s with an interval of 0.025 s	
M5		=v_initial*COS(RADIANS(initial_angle))
N5		=v_initial*SIN(RADIANS(initial_angle))
O5		=SQRT(M5^2+N5^2)
P5	Settings = 0 (zero)	
Q5	Settings = 0 (zero)	
M6		=M5-b*M5*O5*dt
N6		=N5-(g+b*N5*O5)*dt
O6		=SQRT(M6^2+N6^2)
P6		=P5+M6*dt
Q6		=Q5+N6*dt
M7		=M6-b*M6*O6*dt
N7		=N6-(g+b*N6*O6)*dt
O7		=SQRT(M7^2+N7^2)
P7		=P6+M7*dt
Q7		=IF(Q6>0;Q6+N7*dt;NA())

The next step is to create a graph with a spreadsheet to show the relationship between the horizontal position function and the vertical position function.

Falling Objects in the Air
The first step is to determine and input the quantities used in the calculations. In cells A4 to D9, input physical quantities, namely gravity (g), number of steps (n), time interval (dt),

terminal velocity ($v_{terminal}$), mass (m), and coefficient of drag (b). For the value of b input the formula

$$b = \frac{mg}{v_{terminal}^2}$$ in excel with =m*g/vterm^2

	A	B	C	D	
1					
2	**Quantity**	**Symbol**	**Value**	**Unit**	
3	Gravity	g =	9,81	m/s^2	
4	Step	n =	5		
5	Time Interval	dt =	0,1	s	
6	Terminal Velocity	v_{term} =	100	m/s	
7	Mass	m =	25	kg	
8	Drag Coefficient	b =	0,024525	kg/m	

Figure1. *Input Parameter Display*

In cells A13 to D13, enter the quantities of time, position, velocity, and acceleration. After that, cell A14 as the starting time, B14 as the starting position, and C14 as the initial speed, each input the value 0. Next, in cell A14, input the following formula

=A14+dt

then copy-paste until cell A200. In cell D14, input the following formula a=g-

=g-(C14/vterm)^n

For the cells below it up to D200, input the following formula:

=g*(1-(C15/vterm)^n)

Next, in cell B15, input the following formula

=B14+(C14+C15)*s/2

then copy-paste until cell A200. In cell C15, input the following formula:

=C14+D14*dt

then copy-paste until cell A200.

Particle Energy in a One-Dimensional (1-D) Box

Suppose a particle is free to move in a one-dimensional region. Schrodinger's Equation,

$$-\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2} = E\psi(x)$$

The solution to this equation is

$$\psi = Ae^{ikx}$$

with$k = \pm\frac{\sqrt{2mE}}{\hbar}$. The general solution of this equation is

$$\psi = Ae^{ikx} + Be^{-ikx}$$

where A and B are arbitrary constants, determined by applying the boundary conditions. Suppose that the particle is confined to the region $x = 0$ dan $x = a$. Next, the potential $V(x) = 0$ for $0 \leq x \leq a$ and $V(x) = \infty$ for the others. The time-independent Schrodinger equation is given by

$$-\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2} + V(x)\psi(x) = E\psi(x)$$

For the area outside the box, $V(x) = \infty$ and $\psi(x) = 0$. For the area within the box, the time-independent Schrodinger Equation is written as

$$\frac{\hbar^2}{2m} \frac{d^2\psi(x)}{dx^2} = E\psi(x)$$

The boundary condition, $\psi(0) = \psi(a) = 0$. General solution,

$$\psi(x) = A \sin kx + B \cos kx$$

At $x = 0$, $\psi(0) = B = 0$. At $x = a$, $\psi(a) = 0$, then $A \sin ka = 0$ or $k = \frac{n\pi}{a}$, here n is an integer. So, the solution to the time-independent Schrodinger equation that satisfies the boundary conditions is

$$\psi_n(x) = A \sin \frac{n\pi}{a} x$$

with $n = 1,2,3,\cdots$. Using normalization conditions, the constant A is obtained $A = \sqrt{\frac{2}{a}}$, so that

$$\psi_n(x) = \sqrt{\frac{2}{a}} \sin \frac{n\pi}{a} x$$

(Griffiths & Schroeter, 2017).

To visualize the particle wave function in a one-dimensional box, enter the wave function formula $\varphi_n(x) = \sqrt{\frac{2}{a}} \sin\left(\frac{n\pi}{a} x\right)$ and the probability $|\varphi_n(x)|^2$ in cells D8 and E8 on an excel worksheet.

$$\text{=SQRT(2/\$B\$8)*SIN(RADIANS((\$C\$6*180*C8)/\$B\$8))}$$

and

$$\text{=ABS(D8^2)}$$

Radioactive Decay
The rate of radioactive decay is given by

$$\text{Rate of Change} = \frac{dN}{dt} = -\lambda N$$

where $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$ is the decay constant. By integrating the rate of change equation, it is obtained (Halliday, Resnick, & Walker, 2010)

$$N(t) = N_0 e^{-\lambda t}$$

If $P(t) = 1 - e^{-\lambda t}$ is the probability of decay, then we get $\lambda = -\ln(1 - P)$.

3. RESULT AND DISCUSSION

Learning with spreadsheets is a learning tool in MS Excel with simple functions that can produce simulations or visualizations of equations in physics. In visualization with spreadsheets, constants or data can be replaced, and it will produce different visualizations quickly.

Projectile Motion
In simulating projectile motion using a spreadsheet, we can obtain a graph that visualizes Projectile's position at any given time. We will show a projectile motion simulation with no air resistance and with air resistance. In this case, the x and y positions of the projectile depend

on the initial velocity parameter. Changes to the initial speed and starting angle of the shot can be made using the scrollbar.

In Figure 2, columns I and J are the values of x and y respectively, starting with a zero value, i.e., from cells I5 to I119 and J5 to J119 which change at each time interval of 0.025 s. To graph the x and y functions, using the values calculated in columns I and J, we must select cells I5 through I119 and J5 through J119 and select the Insert Chart button. Next, we choose a scatter graph and a scatter with smooth lines.

Figure 2 shows the graphs for the x and y positions for the predefined parameters and initial conditions.
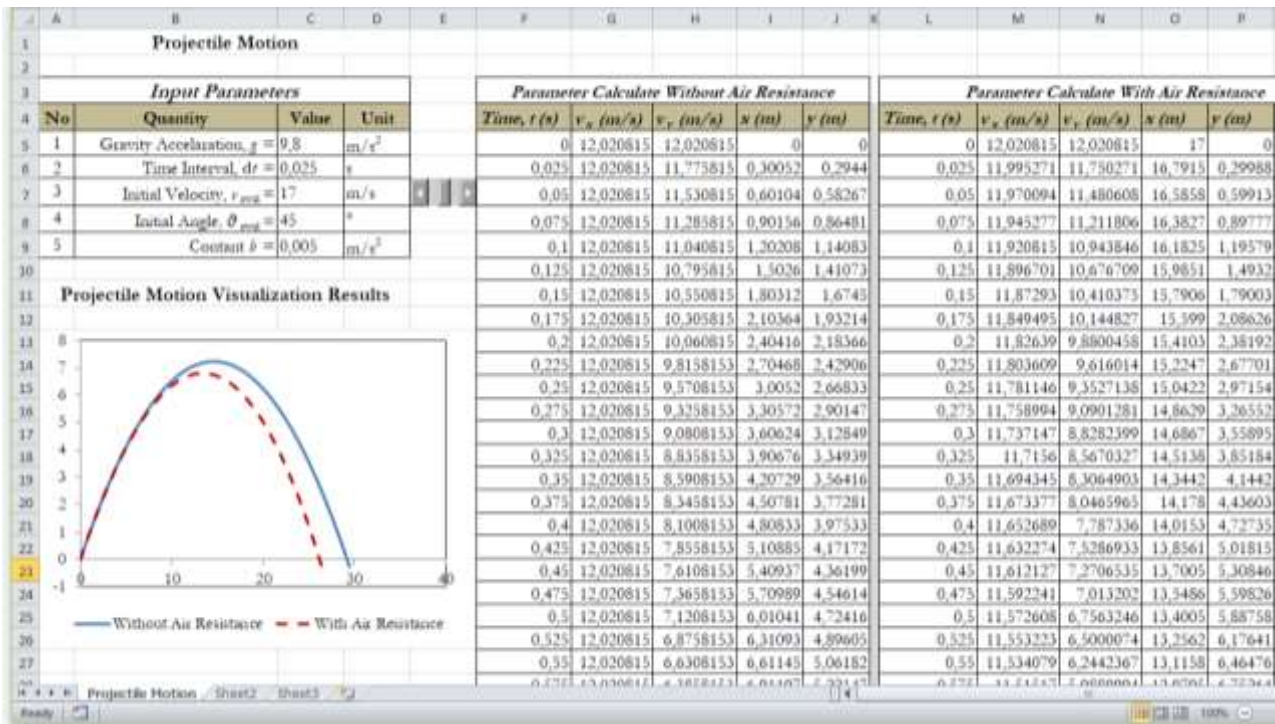
Projectile Motion

Input Parameters

No	Quantity	Value	Unit
1	Gravity Acceleration, $g=$	9.8	m/s^2
2	Time Interval, $dt=$	0.025	s
3	Initial Velocity, $v_{awal}=$	17	m/s
4	Initial Angle, $\theta_{awal}=$	45	°
5	Constant $b=$	0.005	m/s^2

Projectile Motion Visualization Results

— Without Air Resistance   – – With Air Resistance

Parameter Calculate Without Air Resistance

Time, t (s)	v_x (m/s)	v_y (m/s)	x (m)	y (m)
0	12.020815	12.020815	0	0
0.025	12.020815	11.775815	0.30052	0.2944
0.05	12.020815	11.530815	0.60104	0.58267
0.075	12.020815	11.285815	0.90156	0.86481
0.1	12.020815	11.040815	1.20208	1.14083
0.125	12.020815	10.795815	1.5026	1.41073
0.15	12.020815	10.550815	1.80312	1.6745
0.175	12.020815	10.305815	2.10364	1.93214
0.2	12.020815	10.060815	2.40416	2.18366
0.225	12.020815	9.8158153	2.70468	2.42906
0.25	12.020815	9.5708153	3.0052	2.66833
0.275	12.020815	9.3258153	3.30572	2.90147
0.3	12.020815	9.0808153	3.60624	3.12849
0.325	12.020815	8.8358153	3.90676	3.34939
0.35	12.020815	8.5908153	4.20729	3.56416
0.375	12.020815	8.3458153	4.50781	3.77281
0.4	12.020815	8.1008153	4.80833	3.97533
0.425	12.020815	7.8558153	5.10885	4.17172
0.45	12.020815	7.6108153	5.40937	4.36199
0.475	12.020815	7.3658153	5.70989	4.54614
0.5	12.020815	7.1208153	6.01041	4.72416
0.525	12.020815	6.8758153	6.31093	4.89605
0.55	12.020815	6.6308153	6.61145	5.06182

Parameter Calculate With Air Resistance

Time, t (s)	v_x (m/s)	v_y (m/s)	x (m)	y (m)
0	12.020815	12.020815	17	0
0.025	11.995271	11.750271	16.7915	0.29988
0.05	11.970094	11.480608	16.5858	0.59913
0.075	11.945277	11.211806	16.3827	0.89777
0.1	11.920815	10.943846	16.1825	1.19579
0.125	11.896701	10.676709	15.9851	1.4932
0.15	11.87293	10.410373	15.7906	1.79003
0.175	11.849495	10.144827	15.599	2.08626
0.2	11.82639	9.8800458	15.4103	2.38192
0.225	11.803609	9.616014	15.2247	2.67701
0.25	11.781146	9.3527138	15.0422	2.97154
0.275	11.758994	9.0901281	14.8629	3.26552
0.3	11.737147	8.8282399	14.6867	3.55895
0.325	11.7156	8.5670327	14.5138	3.85184
0.35	11.694345	8.3064903	14.3442	4.1442
0.375	11.673377	8.0465965	14.178	4.43603
0.4	11.652689	7.787336	14.0153	4.72735
0.425	11.632274	7.5286933	13.8561	5.01815
0.45	11.612127	7.2706535	13.7005	5.30846
0.475	11.592241	7.013202	13.5486	5.59826
0.5	11.572608	6.7563246	13.4005	5.88758
0.525	11.553223	6.5000074	13.2562	6.17641
0.55	11.534079	6.2442367	13.1158	6.4647

Projectile Motion / Sheet2 / Sheet3

Figure 2. General Appearance of Projectile Motion Visualization

For the next step, create a ScrollBar on each Input Parameter of the projectile motion visualization. To create a scrollbar, we will use the "Developer" menu. How to enable the Developer menu:

1. Open the MS Excel application
2. Click the "Office Button" located in the upper left corner of the worksheet. Then select Excel Options at the bottom.
3. After that, a dialog box will appear, select the popular section and put a checkmark (√) on the "Show Developer Tab In The Ribbon".
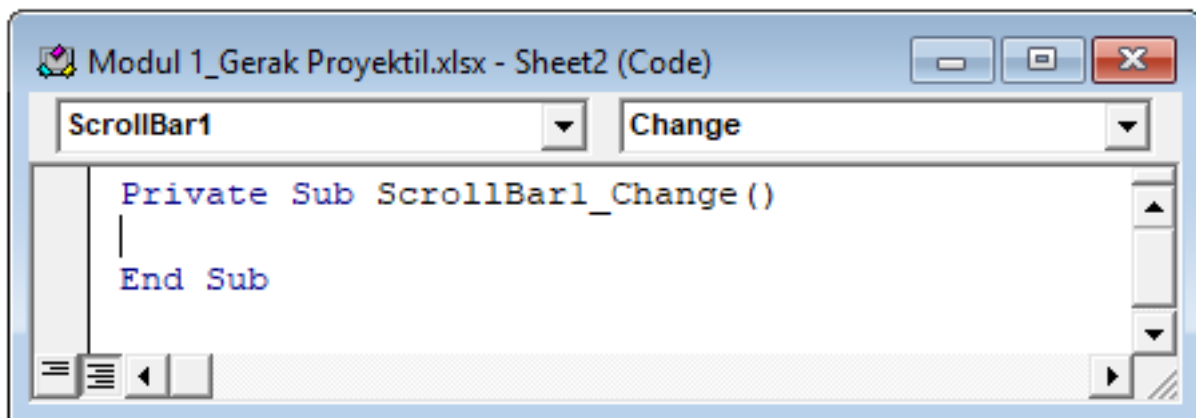4. Then click OK.
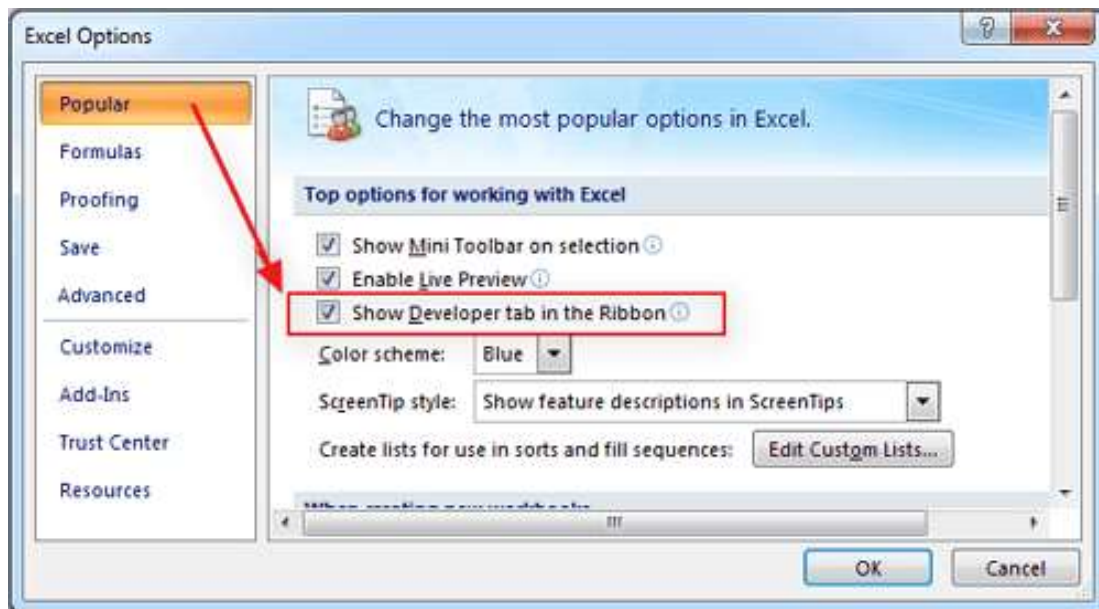
To create a Scrollbar for the initial speed parameter. How to create a ScrollBar:

1. Click the Developer Tab
2. In the "Controls" group, click "Design Mode". Then click "Insert" then select "Scroll bar (ActiveX Controls).
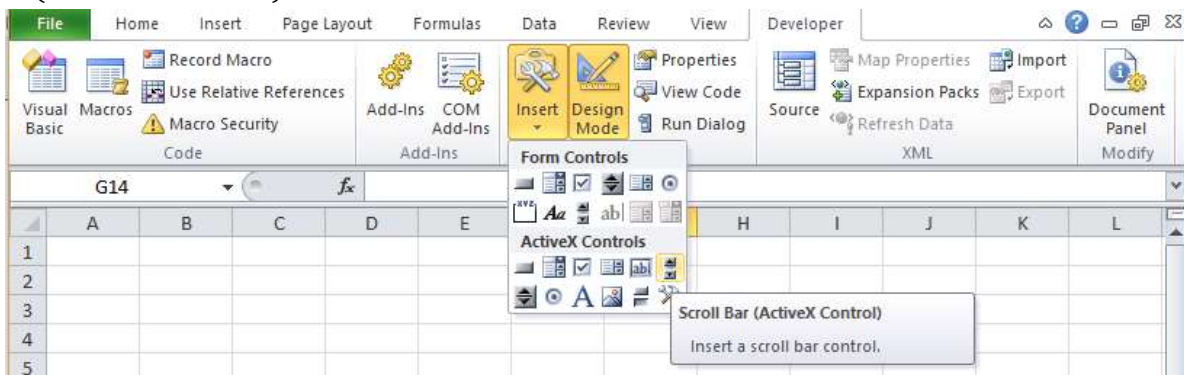
After that, hover over cell F9 in the parameter deviation section, then drag it to the right without releasing it until it looks like


Type the following code:

```
Private Sub ScrollBar1_Change()
' Initial conditions
Cells(7, 3) = ScrollBar1.Value / 0.2
End Sub
```

Description:

- ScrollBar1's text is that the scrollbar created is the first.
- The text "Initial speed" is the parameter to be varied.
- (7, 3) is the location of the value cell to be varied, with the meaning 7 is a row and 3 is a column. In general, this value is in cell C7.
- The value of 0.2 is that the value to be displayed is a multiple of 5.
3. After that, click again "Design Mode".

Figure 3 and Figure 4 are respectively the results of visualizing the motion of a projectile with a constant initial velocity and a different starting angle, and a different initial velocity and a fixed or the same starting angle.
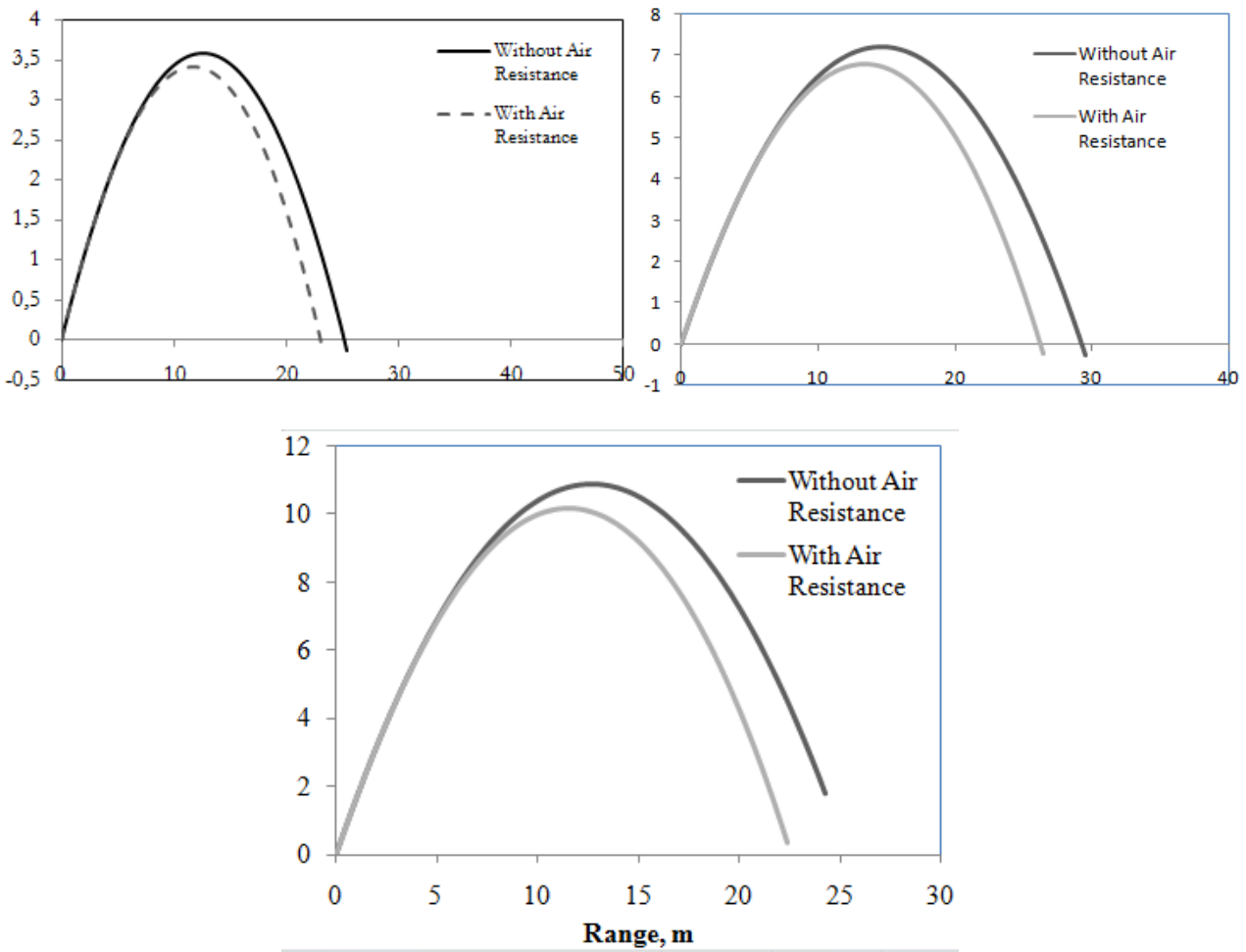
Figure 3. Visualization of projectile motion with different starting angle of shot $\theta = 30^0$, $\theta = 45^0$, and 60^0
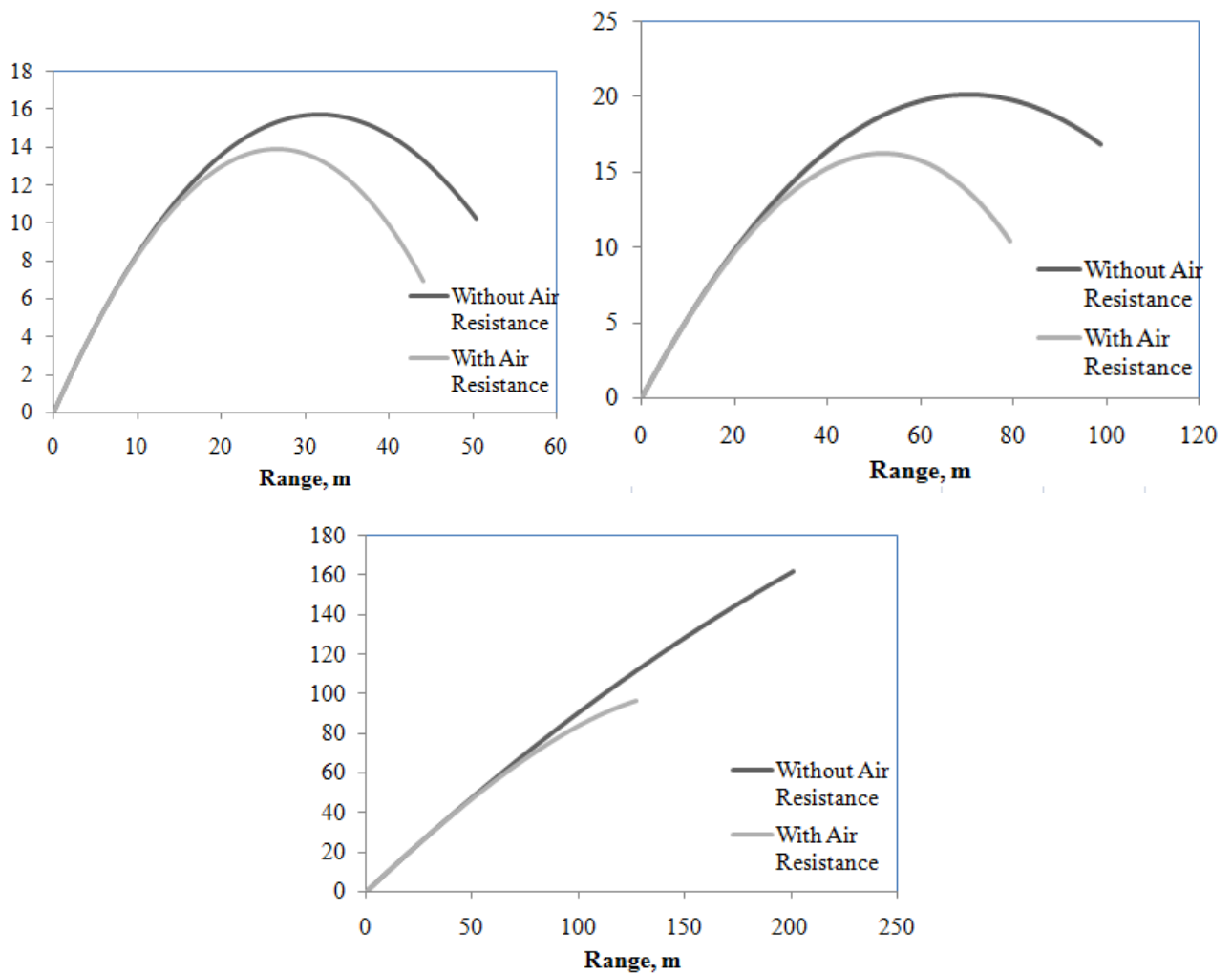
Figure 4. Visualization of projectile motion with velocity difference θ = 30⁰, v = 25 m/s, v = 40 m/s, θ = 30⁰, v = 100 m/s.

Based on Figure 3, it appears that the difference in the initial angle affects the horizontal range with the same initial velocity of 17 m/s. A larger initial angle of 45⁰ is greater than an angle of 30⁰. The same thing is also shown in Figure 3, which ~~visualizes of~~ projectile motion with a constant difference in initial velocity and initial angle. The visualization results show that the greater the initial velocity, the greater the horizontal range, and the maximum height.

Falling Objects in the Air

Figure 5 shows a general visualization display of free-fall motion with terminal velocity v_{term} = 20 m/s. The resistance coefficient b is calculated using the formula m*g/vterm^2, obtained 0.613125 kg/m. The value of this resistance coefficient will change with changes in the terminal velocity v_{term} and the object's mass m.
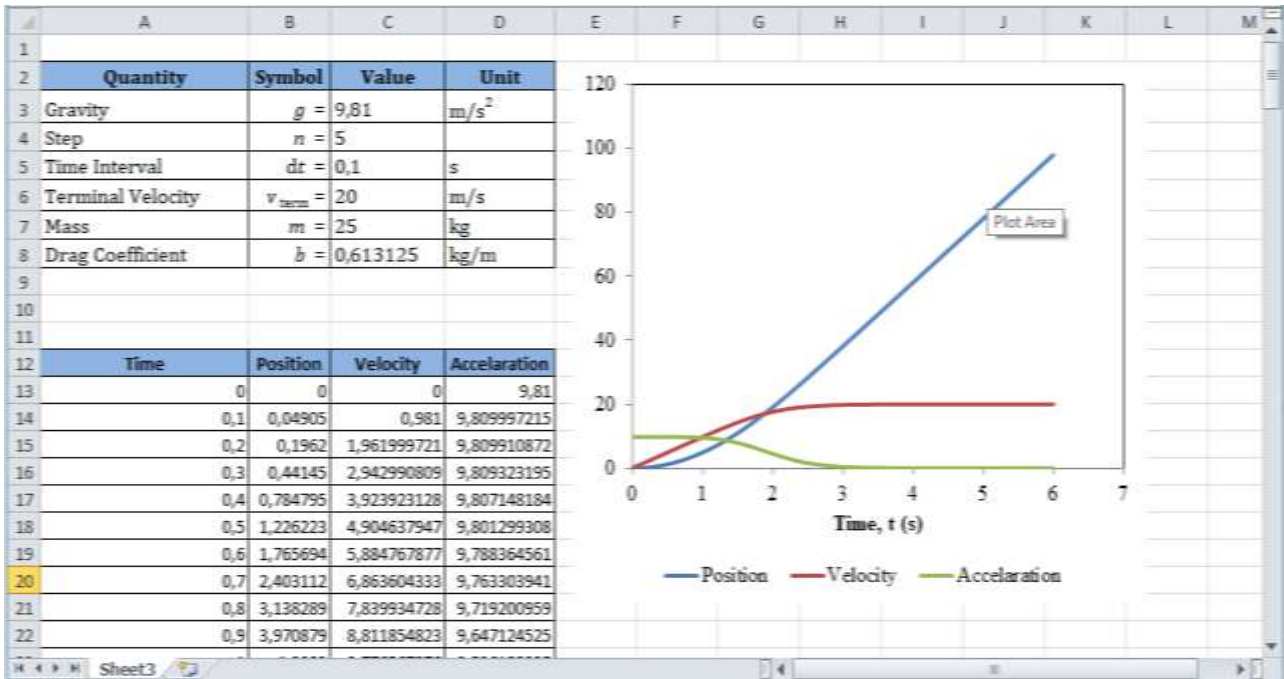
Figure5. General view of free-fall motion visualization $v_{term} = 20$ **m/s**

Figure 6 is the result of the visualization of free-fall motion with different terminal velocity values, namely 5 m/s, 20 m/s, 45 m/s, and 75 m/s.
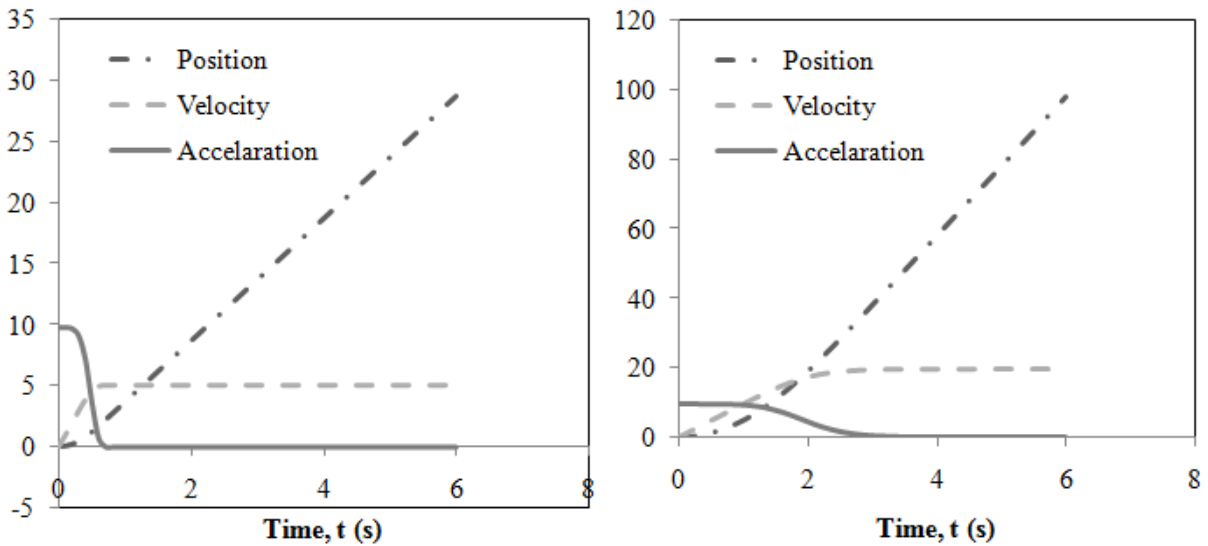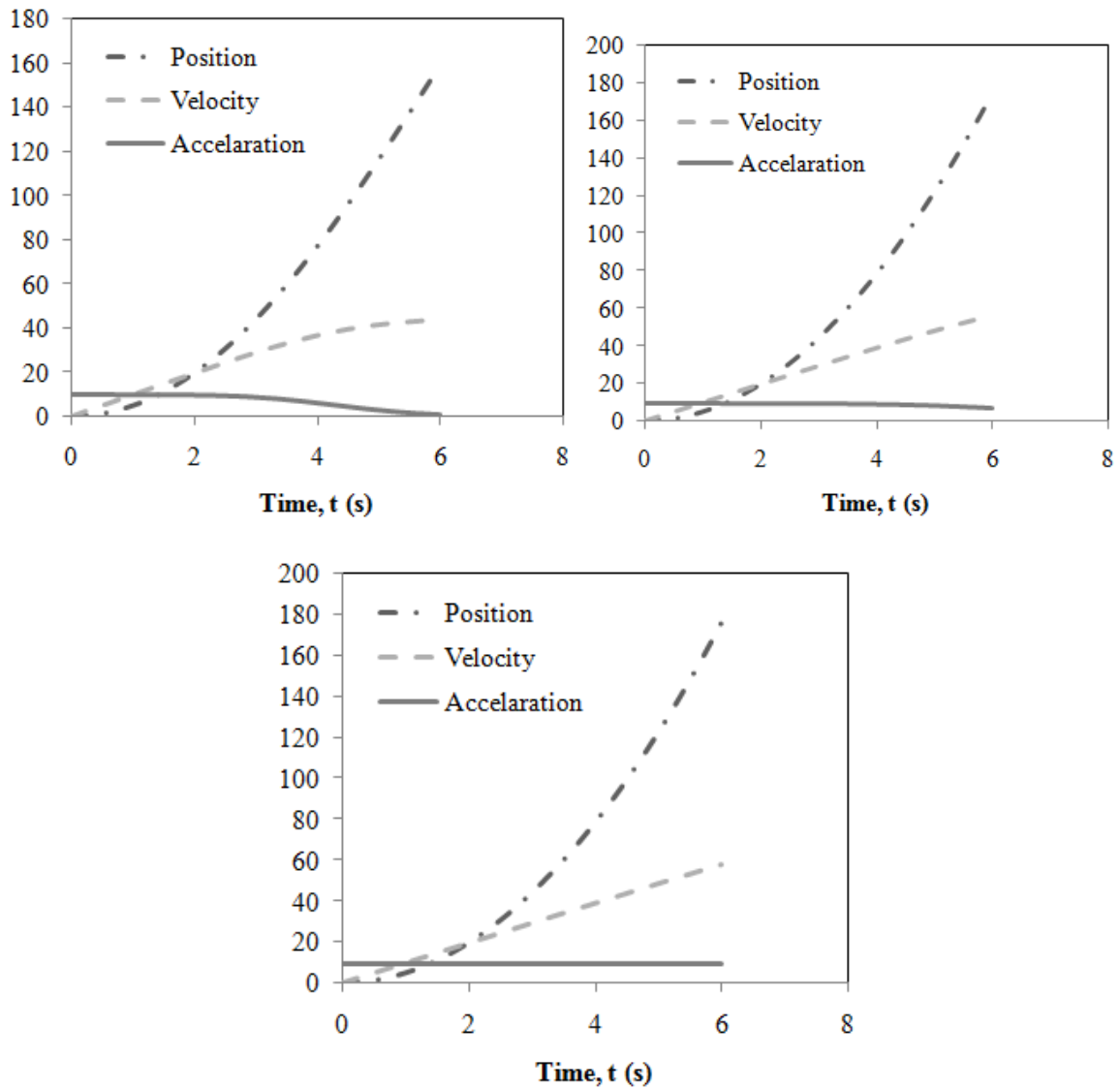
Figure 6. Visualization of free fall motion with different terminal velocities of 5 m/s; 20m/s; 45 m/s; 75 m/s; and 100 m/s.

Based on Figure 6, it appears that increasing the value of terminal velocity affects the graph of position, velocity, and acceleration concerning a given function of time. Students can see the change in the value in columns B13, C13, and D13. The results of the visualization using a spreadsheet show that the larger the terminal velocity value, the more curved the graph of the position versus time function, while the velocity and acceleration graphs tend to be linear.

Particle Energy in a One-Dimensional (1-D) Box

Figure 7 shows a graph of the wave function and probability with different values of n, i.e., $n = 1$ to $n = 4$.

For $n = 1$, The wave function of the particle is

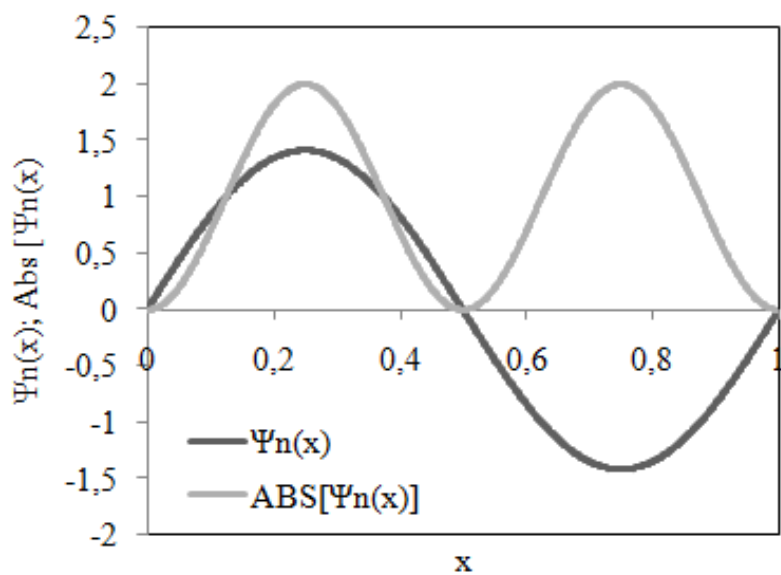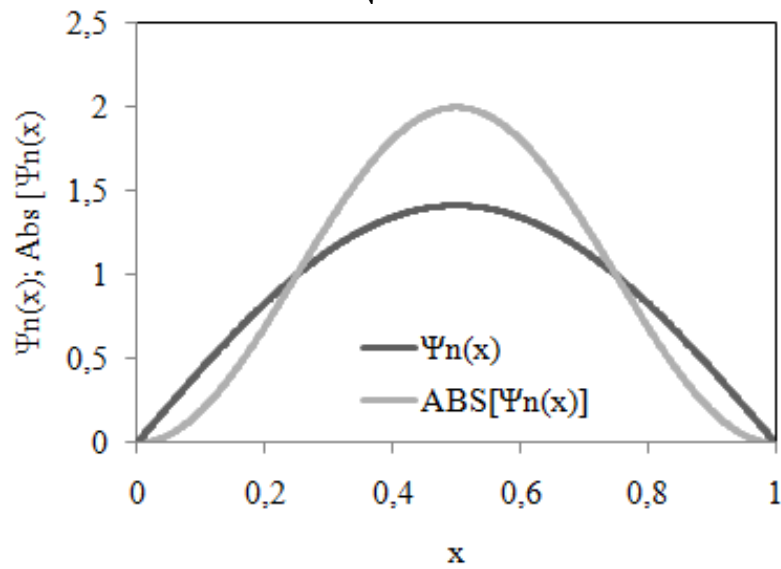$$\psi_1 = \sqrt{\frac{2}{a}}\sin\frac{\pi}{a}x$$

for $n = 2$is
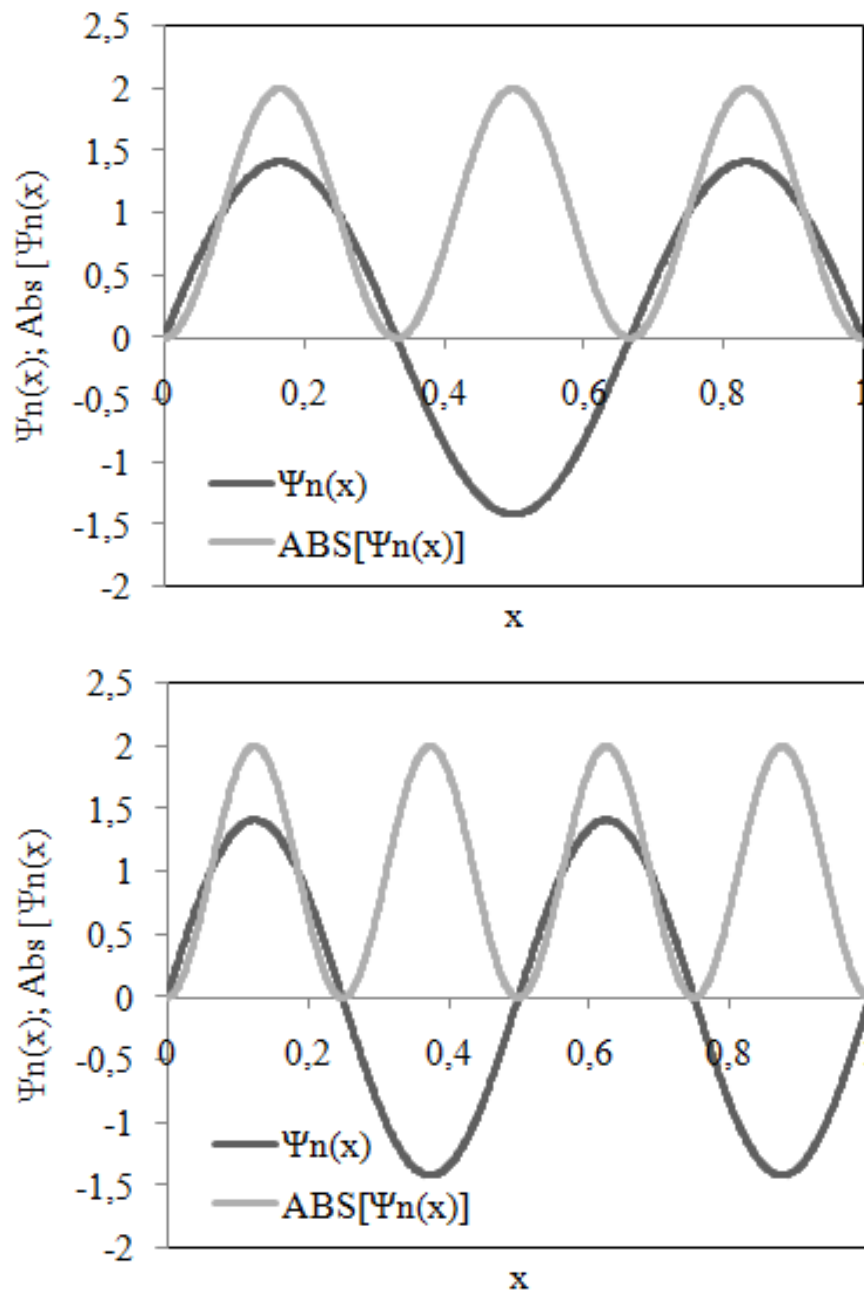
$$\psi_2 = \sqrt{\frac{2}{a}} \sin \frac{2\pi}{a} x$$

for $n = 3$is

$$\psi_3 = \sqrt{\frac{2}{a}} \sin \frac{3\pi}{a} x$$

and $n = 4$is

$$\psi_4 = \sqrt{\frac{2}{a}} \sin \frac{4\pi}{a} x$$

Firgure 7. Graph of a wave function with $n = 1, 2, 3$ and 4.

Based on Figure 7, it appears that as the quantum number increases, the wave function forms oscillations. For $n = 2$, the wave function is zero at $x = \frac{a}{2}$ which is called the node of the wave function. For the case of particles in a one-dimensional box, the number of nodes is $n - 1$. So, at $n = 1$ there is no node, $n = 2$ there is 1 node, $n = 3$ there are 2 nodes, and $n = 4$ there are 3 nodes, and so on. The probability of finding a wave-particle in the one-dimensional region between $x = 0$ to $x = a$ is proportional to the square of the wave function.

Nuclear Radioactive Decay
Figure 8 shows the radioactive decay simulation result with different decay probability values.
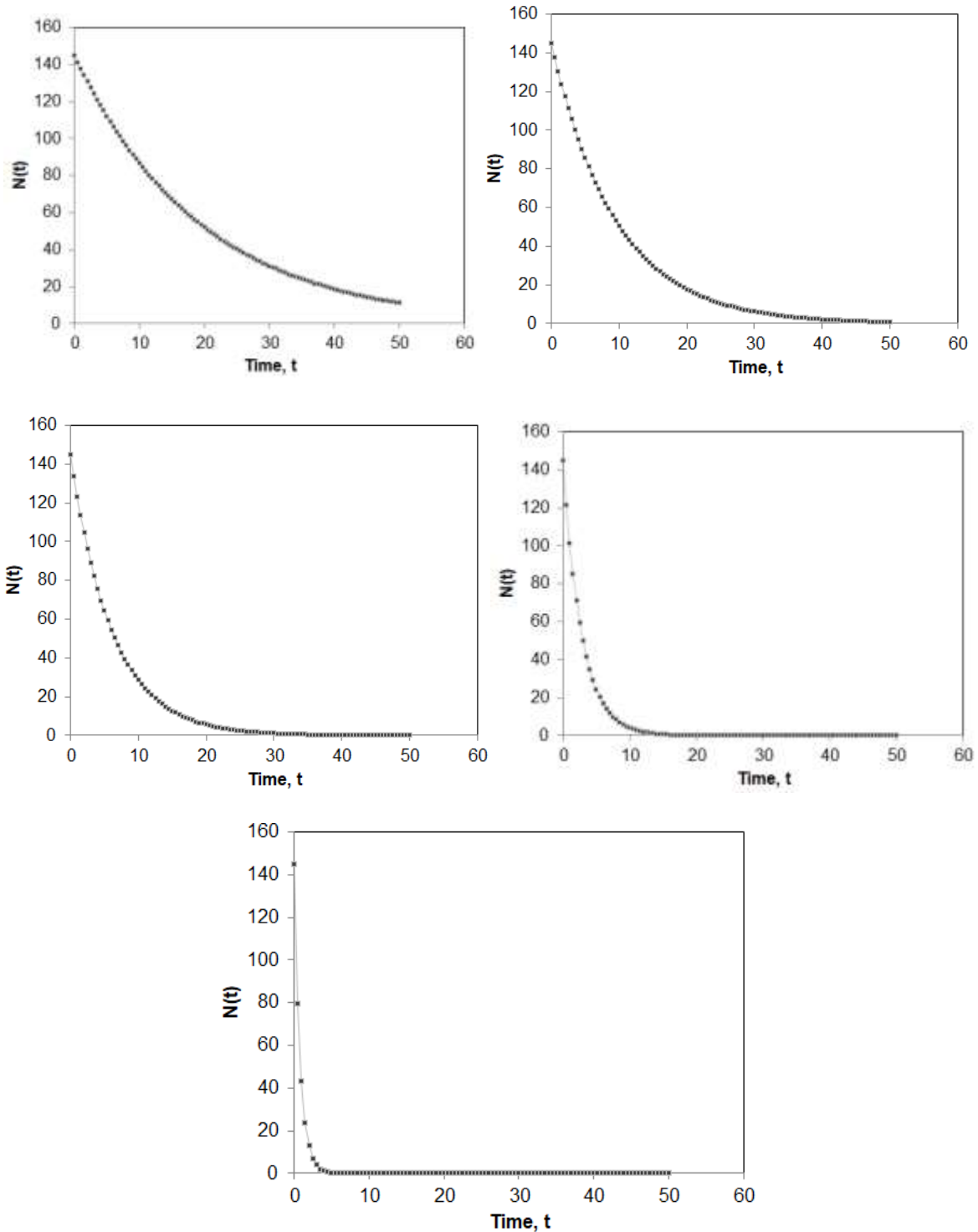
Gambar 8. Grafik

Based on Figure 8, the decay time of the nucleus with the number $N_0 = 145$, and the different probability values of P show different graphs. The larger the value of P, the decay time of the nucleus occurs faster than the value of small P.

4. CONCLUSION

Excel spreadsheets are very important in learning and understanding physics through graphical visualization and simulations. In this article, we show how an excel spreadsheet is used to create visualize of projectile motion, free-fall motion, particle wave functions in one-dimensional squares, and radioactive decay. The results in this study indicate Spreadsheet

are very useful for effective physics learning, which can help students to learn physics concepts effectively.

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