Teaching free-falling motion with LibreOffice Calc

K. Sornbundit
Ratchaburi Learning Park, King Mongkut's University of Technology Thonburi (Ratchaburi), Ratchaburi 70150, Thailand.

Received 9 January 2024; accepted 28 March 2024

The aim of this work is to demonstrate how to use `LibreOffice Calc`, a freeware spreadsheet, to teach physics of free-falling motion. Although free-falling motion is experienced in our daily lives, students often misunderstand the calculations, mainly because of the use of signs for related physical parameters. For example, the velocity can be positive, negative, or even zero, depending on the direction of motion. To help students learn, we have used the embedded VLOOKUP function in `LibreOffice` to create a simulation of the object's trajectory. We have found that the software can be used to create snapshots of consecutive vertical motions of the object. The direction of the object's movement can be determined using the IF function. Moreover, the software can be used to solve equations that are often found in problems in this class. By using the Goal Seek function, the numerical value of the parameter of interest can be obtained.

Keywords: `Libreoffice calc`; free-falling motion; teaching physics; simulation; goal seek function.

DOI: https://doi.org/10.31349/RevMexFisE.22.010204

1. Introduction

Currently, computer software has been used in teaching physics at all levels of education because it has the ability to do mathematical calculations, analyse data, and create visualizations. Some of these software programs require a fee, while others are free to use. Spreadsheet software is a class of software that has tables and built-in functions to perform calculations. Experts can even write codes within this software to perform more complex calculations. One of the most famous spreadsheet software programs is `Microsoft Excel`.

`Microsoft Excel` has been used in teaching physics since 1988 [1]. Many researchers have suggested using `Microsoft Excel` in many areas of physics [2-22]. However, this software is requiring the payment. This makes it suitable for institutional or commercial usage. For personal use, especially for learning purposes, it is worth considering an alternative software that is free to use.

`LibreOffice Calc` is a freeware spreadsheet software program in the `LibreOffice` suite. It has mathematical calculation and graphing capabilities similar to Microsoft Excel. A very recent article has demonstrated `LibreOffice Calc`'s ability to simulate the two-body pursuit problem using the Goal Seek function [18]. This opens up the opportunity for the software to be used in many other physics problems.

The study of vertical motion without considering the effect of air, which is called free-falling motion, is one of the important physics concepts for the introductory university physics course. In the author's experience, students often misunderstand the calculations for this topic. The most common mistake is about the sign of vector quantities such as initial velocity u, final velocity v, vertical displacement, and gravitational acceleration (g). Most textbooks specify the direction of g as negative because it is inward to the Earth. Therefore, any vector quantities that have the opposite direction to g will have a positive value. Vertical displacement can be negative if the object's final position is lower than its initial position. Students often assign a negative value to g, but all other quantities are considered positive. The author usually prepares exams to test students' understanding of sign conventions, and has found that most students are incorrect. One explanation is that students cannot visualize the trajectory of a vertically moving object.

In physics, if we cannot visualize the problem, it is nearly impossible to solve it. Another issue is that some students struggle to solve equations due to a lack of mathematical skills. In certain problems, they are required to work with quadratic functions, which can be challenging for some students to solve.

In the article, we propose the use of the freeware spreadsheet `LibreOffice Calc` to simulate the vertical motion of an object without considering the effects of air and to use the Goal Seek function to solve common equations found in this topic.This approach can be applied in both secondary school and introductory physics courses at the university level.

2. `LibreOffice` for studying free-falling motion

`LibreOffice` was used to simulate the vertical motion of an object from the top of the building. The Goal Seek function was also utilized to solve the equation and find the time the object travels in the air before hitting the ground.

2.1. Vertical motion simulation

The situation of interest is the vertical motion of an object from the top of a building. This situation was chosen because most students confuse the signs of velocity, gravitational acceleration, and vertical displacement. The sign of an object's velocity can be positive, negative, or even zero (when the object has reached its maximum height), depending on the direction of motion. The vertical displacement can also be positive, negative, or even zero, depending on the object's relative position with respect to the starting point (the top of

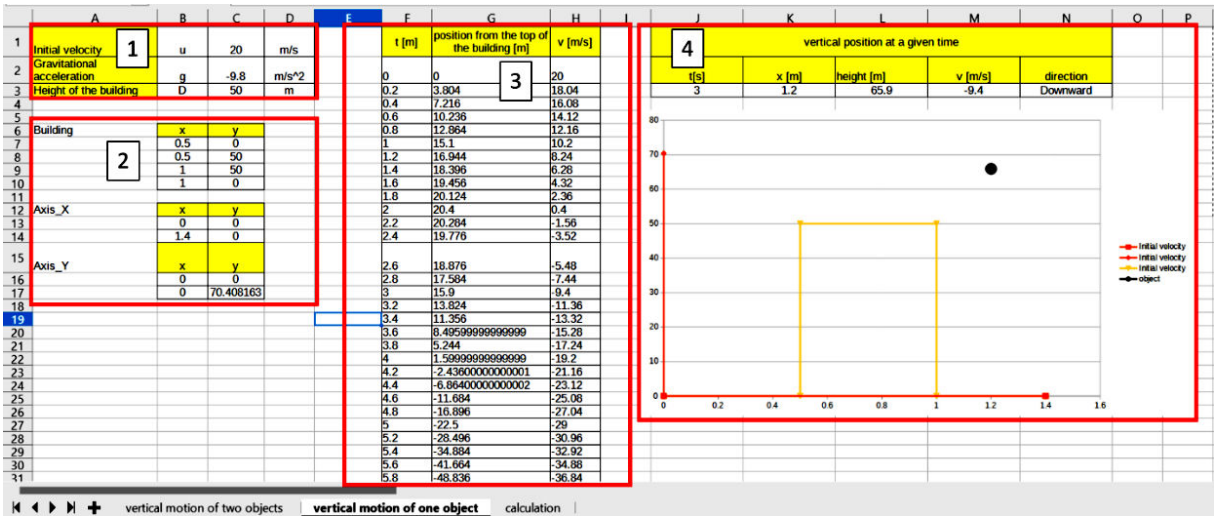

FIGURE 1. Layout of the worksheet for simulating the vertical motion of the object.

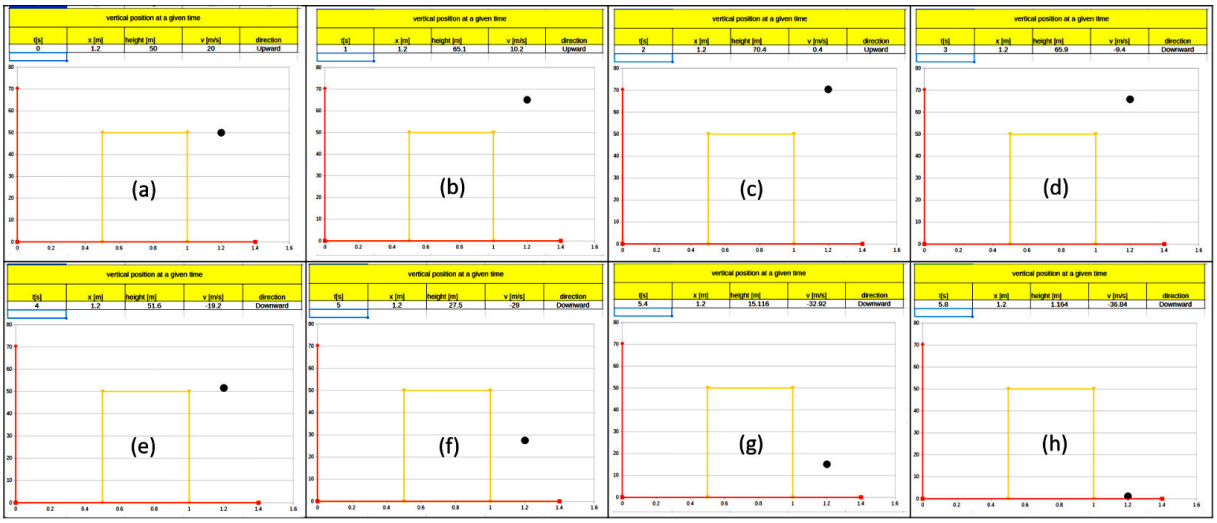

FIGURE 2. Free-falling motion of the object at 0, 1, 2, 3, 4, 5, 5.4, and 5.8 seconds, respectively.

the building). Therefore, simulating the motion is worthwhile to help students learn about these concepts.

The worksheet layout for this problem is shown in Fig. 1. There are four main portions of the worksheet. The first is about identifying the values of initial velocity u, gravitational acceleration g, and the height of the building D. Note that the units of the quantities are shown in column D. The building and the axes can be drawn by specifying their coordinates in the second panel. The third panel is about calculating the vertical position of the object measured from the top of the building and the corresponding velocity. The formulas used are shown in Table I. The simulation is displayed in the fourth panel. In this panel, a user has to enter the value of time from the third panel. The height of the object at that time will be presented in cell L3 using the VLOOKUP function (see formula in Table I). The object is represented by the black dot, which is plotted using the coordinates in cells K3 and L3. Note that the object is drawn on the right side of the building for simplicity in viewing. The direction of motion can be found in cell N3. Snapshots of the vertical motion of the object are shown in Fig. 2a)-h). From these figures, we can see that the object was moving upward until it reached its maximum height and then moved downward to the ground.

2.2. Use of goal seek function

The use of the Goal Seek function can be shown in solving the time interval from the top of the building to the ground. To do this, one may use the equation:

$$S = ut + \frac{1}{2}gt^2, \tag{1}$$

where S is the displacement, u is the initial velocity of the object, g is the gravitational acceleration and t is the time. From our experience, there are two main difficulties for this problem. First, most students are confused by the sign of

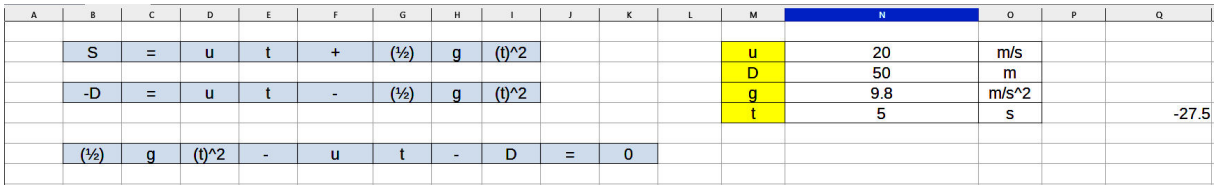

FIGURE 3. Layout of the worksheet for solving the time interval before reaching the ground.

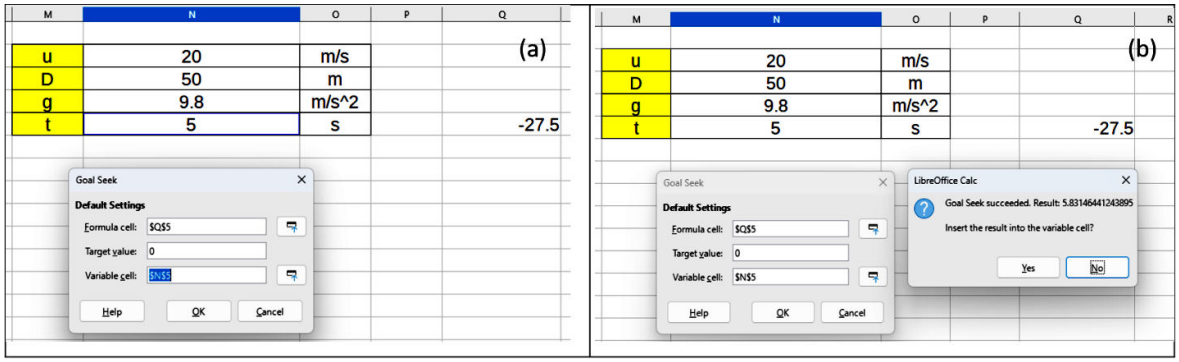

FIGURE 4. The use of the Goal Seek function in calculating the time interval before reaching the ground.

each parameter. Second, some students cannot solve Eq. (1). If the building height is D, Eq. (1) can be solved as follows:

$$\frac{1}{2}gt^2 - ut - D = 0. \tag{2}$$

The steps for solving for t and using the Goal Seek function are shown in another worksheet of `LibreOffice Calc`, see Fig. 3. Equation (2) can be solved using the Goal Seek function. To do this, type the equation to be solved into a cell. In our worksheet, we put the left side of Eq. (2) in cell Q5.

The function is accessed by choosing the menu Tools > Goal Seek. A popup window will appear, see Fig. 4a). The goal of the Goal Seek function is to find the parameter that makes the equation true. In the popup, we must identify the cell containing the equation we need to solve in the formula cell box. In the worksheet, we chose cell Q5. In the target value box, we put zero because the right side of Eq. (2) is zero. The variable cell box is the box for the cell containing the value of the parameter we need to adjust to make the equation true. In our worksheet, it is time and the cell is N5, see Fig. 4a). Values of the other parameters are shown in cells N2-N4. To use the Goal Seek function, we must guess a value of time that is close to the answer and put it in cell N5. This can be done by inspecting the object's simulation in panel 4 of Fig. 1. Then click OK. A popup window will appear, see Fig. 4b). This popup tells us about the value of time that fits our condition.

TABLE I. Displays the cells, terms, descriptions, and command/values of parameters used in worksheets.

Cell	Term	Description	Command/value
For worksheet in Figure 1			
F2	t	Time [s]	
G2	S	Position from the top of the building [m]	=$C$1*$F2+(0.5*$C$2*$F2^2)
H2	v	Velocity at a particular time [m/s]	=$C$1+$C$2*$F2
C1	u	Initial velocity [m/s]	20
C2	g	Gravitational acceleration [m/s^2]	-9.8
C3	D	Height of the building [m]	50
C17		The maximum value if y axis	=C3+(C1^2)/(2*9.8)
L3		The position of object at a specific time	=VLOOKUP(J3,$F$2:$H$31,2)+C3
M3		The velocity of the object	=VLOOKUP(J3,$F$2:$H$31,3)
N3		The direction of the moving of the object	=IF(M3>0,"Upward","Downward")
For the worksheet in Figure 3			
Q5		The formulation of equation 2	=0.5*N4*(N5^2)-N2*N5-N3

3. Results and discussion

The snapshots of the object's motion at various times are shown in Fig. 2. From these figures, we can see that `LibreOffice Calc` is able to perform a simple simulation for the free-falling motion without requiring intensive programming skills. The use of the VLOOKUP function to search through the table of pre-calculated heights can plot the object at a particular time. By plotting the object at consecutive times, a simulation picture of the trajectory is easily created. The direction of motion can be determined by inspecting the sign of the object's velocity. By applying the IF function to the value of the velocity, the direction of motion is also obtained. This would help students to understand the characteristics of the motion.

The other worksheet shows an example of calculating the time the object travels until reaching the ground, which is a common problem to test understanding of the theory. This worksheet shows a process of calculation from choosing the starting equation to solving the equation by using the Goal Seek function. To demonstrate the use of the Goal Seek function, the problem of throwing an object from the top of a building of height 50 m at an initial velocity $u = 20$ m/s was used. These parameters were obtained from a physics textbook [23]. In order to find the time that the object travels before hitting the ground, we have to solve Eq. (2). To use the Goal Seek function, a time of 5 s was guessed, as shown in Fig. 4a). By setting the value in the popup window as shown in Fig. 4b), a numerical value of time of about 5.83 s was obtained. This method bypasses the mathematical procedure to quickly obtain the answer. In our view, this spreadsheet is a tool to help students in learning, but solving equations like this by hand is still necessary.

4. Conclusion

In this article, we have presented a method for using the free spreadsheet software LibreOffice Calc to teach free-falling motion. By applying a few available functions, such as VLOOKUP and Goal Seek, we created a simulation of the object's trajectory. Additionally, the software can be used to solve related equations to obtain the numerical value of the time that the object travels before reaching the ground. Instructors can use this worksheet in teaching or preparing tests by varying the values of the parameters. The results will be automatically calculated by the software. Students can also use the worksheet to help their learning.

Acknowledgements

I would like to express my sincere gratitude to the King Mongkut's University of Technology Thonburi (Ratchaburi), for providing me with the opportunity to conduct this research.

1. R. Dory, Spreadsheets for physics, *Computers in physics* **2** (1988) 70. https://doi.org/10.1063/1.168300.
2. E. Adhitama and A. Fauzi, A novel real-time data acquisition using an excel spreadsheet in pendulum experiment tool with light-based timer, *Physics Education* **53** (2018) 035002. https://dx.doi.org/10.1088/1361-6552/aaa355
3. M. I. González, Lens ray diagrams with a spreadsheet, *Physics Education* **53** (2018) 035016. https://dx.doi.org/10.1088/1361-6552/aaacb7
4. I. Grigore, C. Miron, and E. Barna, Didactic tools created with Excel spreadsheets to study motion on an inclined plane, *Romanian Reports in Physics* **68** (2016) 440.
5. I. Grigore and E. S. Barna, Using Excel spreadsheets to study the vertical motion in a gravitational field, *Procedia-Social and Behavioral Sciences* **191** (2015) 2769. https://doi.org/10.1016/j.sbspro.2015.04.259
6. S. K. Katoch, MS-Excel Spreadsheet Applications in Introductory UnderGraduate Physics-A Review, *Journal of Science and Technology* **5** (2020) 48. https://doi.org/10.46243/jst.2020.v5.i3.pp48-52
7. B. Cooke, Some ideas for using spreadsheets in physics, *Physics Education* **32** (1997) 80. https://dx.doi.org/10.1088/0031-9120/32/2/013
8. I. Korsun, S. Kryzhanovskyi, and M. Monchuk, The study of thermometers using Microsoft Excel, *Physics Education* **54** (2019) 065004. https://dx.doi.org/10.1088/1361-6552/ab350c
9. A. Y. Purnama, et al., Particle trajectory simulation using python and spreadsheet as an online learning alternative, *Rev. Mex. Fis. E* **20** (2023) 020202. https://doi.org/10.31349/RevMexFisE.20.020202
10. H. Putranta *et al*., Visualization of body centered cubic energy bands based on spreadsheet-assisted tight binding: Solutions for distance material physics lectures, *Trends in Sciences* **19** (2022) 4590. https://doi.org/10.48048/tis.2022.4590
11. A. Razzak, et al., Root Finding Methods Through GUI in Spreadsheets: Root Finding Methods Through GUI in Spreadsheets, Proceedings of the Pakistan Academy of Sciences: A. *Physical and Computational Sciences* **59** (2022) 37. https://doi.org/10.53560/PPASA(59-1)644
12. R. G. Rinaldi and A. Fauzi, A complete damped harmonic oscillator using an Arduino and an Excel spreadsheet, *Physics Education* **55** (2019) 015024. https://dx.doi.org/10.1088/1361-6552/ab539d
13. I. Singh, K. K. Khun, and B. Kaur, Simulating Fraunhofer diffraction of waves using Microsoft excel spreadsheet, *Physics Education* **53** (2018) 055010. https://dx.doi.org/10.1088/1361-6552/aacd82
14. I. Singh and B. Kaur, Teaching graphical simulations of Fourier series expansion of some periodic waves using spreadsheets, *Physics Education* **53** (2018) 035031. https://dx.doi.org/10.1088/1361-6552/aab447
15. I. Singh, K. K. Khun, and B. Kaur, Visualizing the trajectory of a charged particle in electric and magnetic fields using an Excel spreadsheet, *Physics Education* **54** (2018) 015002. https://dx.doi.org/10.1088/1361-6552/aae3fd
16. I. Singh, B. Kaur, and K. K. Khun, Simulating longitudinal vibrations of coupled oscillator using the fourth-order rungekutta method by programming spreadsheet, *European Journal of Physics* **40** (2019) 045003. https://dx.doi.org/10.1088/1361-6404/ab1666

17. I. Singh *et al.*, Simulating propagation of the resultant electric field vector using 3D vector representations for circular, elliptical and plane-polarised waves, *Physics Education* **56** (2020) 015012. https://dx.doi.org/10.1088/1361-6552/abc638

18. K. Sornbundit, Simulating Two-body Pursuit Problem using LibreOffice, *Journal of Science and Science Education (JSSE)* **6** (2023) 260, https://doi.org/10.14456/jsse.2023.23. https://doi.org/10.14456/jsse.2023.23

19. P. S. Tambade, Trajectory of Charged Particle in Combined Electric and Magnetic Fields Using Interactive Spreadsheets., *European Journal of Physics Education* **2** (2011) 49.

20. Z. Uddin, M. Ahsanuddin, and D. A. Khan, Teaching physics using microsoft excel, *Physics Education* **52** (2017) 053001. https://dx.doi.org/10.1088/1361-6552/aa7919

21. Z. Uddin and M. Hani Zaheer, Simulating Physics Experiments in Spreadsheets-Experimenting with Ohm's Law, The Physics Teacher **57** (2019) 182. https://doi.org/10.1119/1.5092481

22. Z. Uddin *et al.*, Teaching physics using Microsoft Excel-II, Physics Education **58** (2023) 055001. https://dx.doi.org/10.1088/1361-6552/acdbb1

23. R. A. Serway and J. W. Jewett, Physics for Scientists and Engineers with Modern Physics 9th, Cengage Learning (2013).