# Using the Spreadsheet as a Tool
# for Teaching the Fundamentals of Engineering

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## Abstract

This paper will demonstrate how the electronic spreadsheet has been used in a freshman level Fundamentals of Engineering course to prepare students for maximizing their analytical skills with the most ubiquitous analytical tool available today.

## 1. Introduction

The scientific calculator has become obsolete as the standard calculation tool for engineering students. All college students now carry laptops or electronic tablets to all classes. All college students are eager to use their laptop computers for solving engineering problems. Many students are somewhat familiar with the spreadsheet software that is generally available with their computers. However, most students have limited experience with the application of the more sophisticated functions of the spreadsheet for solving engineering problems. The spreadsheet offers a much more robust work space and it is particularly powerful for "what-if" exercises and number crunching problems. Also, the spreadsheet can be effectively used as a teaching forum when used for demonstrating complex calculation procedures. Further, the personal computer also offers access to the internet for universal information such as conversion factors (feet to meters, etc) as well as communicating through email with project team members.

## 2. The Blackboard Intranet

Nearly all colleges now use intranet platforms such as Blackboard for their students. Blackboard and other similar college intranet platforms are designed to exchange course relevant information to students for specific courses. Blackboard becomes a platform for:

- Communication between the professor and the students within the course.
- Exchanging files between professors and students within the course.
- Sending grades to each student exclusively.
- Professor's announcements to keep students in formed of topics to be covered and assignment deadlines with each class.

The Blackboard platform is essential as a vehicle for sending spreadsheet templates to all students. A spreadsheet template is an assignment of problems on a current technical topic to be completed by the students.

Generally, a technical problem is defined on a spreadsheet and the student proceeds to solve the problem on the same spreadsheet and then returns his (or her) solutions to the professor through the "assignments" link on the Blackboard platform. The professor then retrieves the spreadsheet files from each student through the assignments link. Subsequently, the professor grades and returns the graded solutions to each student individually.

## 3. The Spreadsheet Template Applied

As with other engineering fundamentals courses, the Introduction to Engineering course at Palm Beach State College primarily covers the following engineering topics:

- charting (line charts, column charts and semi-log charts)
- statistics (histograms and normal distribution)
- static load analysis (beams and trusses)
- dynamics (kinematics and kinetics)
- DC circuits & AC circuits (Ohm's Law, Kerchoff's laws and phasors)

## 4. Static Forces Example

In the spreadsheet template example of Figure 1a, static forces are applied and reaction forces must be found. First the student must identify the component vectors and their values using trigonometry functions. Then the student must identify the forces and moments as shown on Figure 1b after selecting a fulcrum and identifying the moments produced. Clockwise moments would be negative and anti-clockwise moments would be positive. A moment table (Moments about A) can then be compiled in a tabular form as shown in Figure 1b. The table is used to calculate the value and direction of the moment at support B on this beam. The reaction vector at support B can then be identified as either positive or negative in direction. In this example, moment M4 is positive (anti-clockwise) indicating that the reaction vector force at B (By) will follow in the positive direction.

All of the calculations are carefully linked so that if force F were changed, then the resulting moment and force at support B will automatically re-calculate. Figure 1c shows that changing force F to 200 N from 50 N will reverse moment and reaction forces on support B. This simple what-if analysis demonstrates the sensitivity of reaction forces and moments to a major change in the given forces on the beam.

## 5. Alternating Current Electric Circuit Example

In Figure 2a, a series AC circuit is illustrated to include a generator, a resistor (R), an inductor (L) and a capacitor (C). For the given generator frequency (f) and the values for the circuit components, the inductive reactance and the capacitive reactance calculations are tabulated as shown. Then these results can be organized into the subsequent "Total Impedance" table of Figure 2a. The first two columns of the impedance table list the individual resistance and reactance components. Then a phasor diagram can be drafted where current is shown as the reference phasor along the real (horizontal) axis for a series circuit. The voltage phasors are oriented at right angles to the current phasor so that voltage leads the current through an inductor (VLI), and current leads voltage through a capacitor (ICV). The impedance table can then show that resistance is placed in the real axis column, inductive reactance ($X_L$) becomes a positive component in the imaginary axis column and the capacitive reactance (Xc) becomes a negative component in the imaginary axis column. In this circuit the net reactance ($Xn = XL + Xc$) becomes negative. The circuit impedance (ZT) becomes the Pythagorean sum of the total resistance and the net reactance ($ZT = sqrt(R^2 + Xn^2)$). The phase angle for the circuit is the arctan of the resistance divided by the net reactance ($\phi = arctan(R/Xn)$). The resulting vector diagram shows the resistance R along the X-axis, the net reactance Xn pointing down along the Y-axis and the impedance ZT forming the phase angle $\phi$ with the X-axis. The calculated results include the circuit current, the voltage drops across each component and the power consumed by the circuit. These results apply when the source generator produces power at 60 Hz.

The calculations are all linked. Students are then enlightened when the source generator frequency is changed to 400 Hz. In Figure 2b, the calculated results show that the positive inductive reactance becomes much greater than the negative capacitive reactance thereby resulting in a net positive reactance (Xn) and a positive phase angle ($\phi$). This result dramatically illustrates how the phase angle for the circuit will respond as a consequence of inductive reactance being directly proportional to circuit frequency whereas capacitive reactance is inversely proportional to circuit frequency. The subsequent calculations then represent the response to the circuit frequency change. This kind of what-if analysis is very instructive in demonstrating how AC circuits will respond to inductive and capacitive components at various applied circuit frequencies.

## 6. Major Tests

Tests are conducted for each major topic with the same file exchange. For example, the "Test #3" template is made available to all students through the assignment link at the beginning of the class. Individual students can retrieve the Test #3 template and immediately re-save the file as "Lastname Test 3". Typically, Test 3 and all other major tests will have four detailed problems to be completed within 90 minutes. They then proceed to solve all problems on the spreadsheet and again re-save the file upon completion. Students send their completed Test 3 files to the professor through the assignments link by the end of the class. As the Test 3 files are returned, they will be listed by Blackboard as files "to be graded". Students are instructed not to leave class until their Test 3 file has been received by the Blackboard site.

As shown on Figure 3, a grading column facilitates the grading process. Because of the grading column, the test files for a class of twenty students can be graded in about four hours allowing for commentary on student errors. After the professor has graded the Test 3 files, the files are then returned to the students individually through the Blackboard "Gradebook". All of the grades are also compiled for the professor on the Blackboard "Full Grade Center". The professor can download the list of grades for each test to organize a separate gradebook for reviewing all grades for all students.

Students can retrieve and review their individual graded tests through the Blackboard Gradebook. This grading feature of Blackboard (also in other platforms) informs students continuously through the term of the status of their grades to date. Students never ask me what their grade to date is because they have continuous access to it. Students can review their grades and let me know if I have made a grading error at any point in the term. The Blackboard platform is an essential vehicle for exchanging spreadsheet files between the students and the professor.

## 7. Number Crunching Problems

Many math and engineering problems are number-crunching problems which can be laborious when using a calculator and paper. In the example of Figure 4, a projectile problem (vertical path only) can be used to illustrate the effects of gravity on a ball over time as it rises and falls. A student can clearly see the inflection point where the first derivative of the displacement equation equals zero (dx/dt = velocity = 0 where <u>Max Height of Ball B = 35.85 ft</u> as highlighted in green). Time for each projectile to impact the ground and the impact speeds shown by split-second time increments are also highlighted.
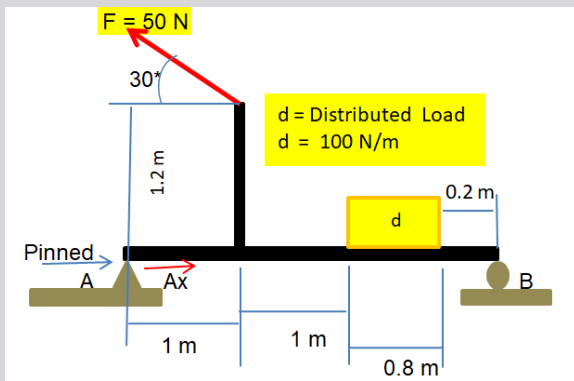
Another number-crunching problem that is facilitated by the spreadsheet is the histogram as shown on Figure 5. Random empirical data can be sorted for classification. A histogram table can organize the data into tabulated categories. Spreadsheet functions can easily translate tabular data into column charts or line charts.

The charting features of spreadsheet software are essential to translating tabular data into illustrative charts for many other kinds of number crunching problems.

## 8. Conclusion

Many other examples can be shown where the spreadsheet is a perfect tool for demonstrating engineering and math principles over a wide range of technical topics.

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Figure 1a: Example Static Forces Problem where F = 50 N

Find the reaction forces Ax, Ay and By. Bx =0
Show and label all vectors and moments.

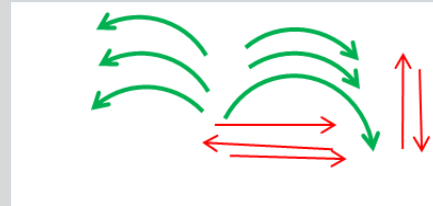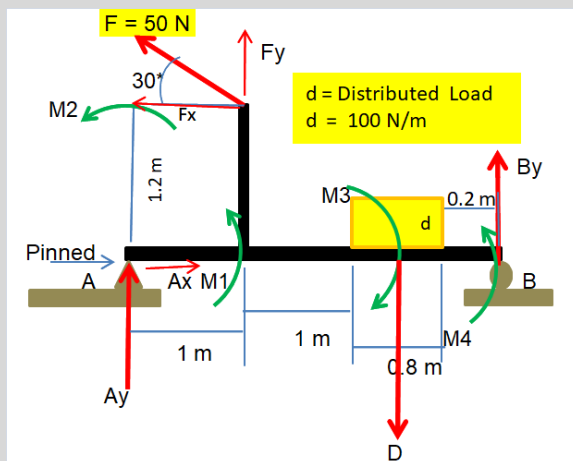| F = | | 50 | N | Given |



Figure 1b: Example Static Forces Solution

Find the reaction forces Ax, Ay and By. Bx =0
Show and label all vectors and moments.

| F = | | 50 | N | Given |
| Fx = | F* cos 30* = | | 43.30 | N |
| Fy= | F* sin 30* = | | 25.00 | N |

| d = | | 100 | N/m | Given |
| D = | | 80 | N | |

Moments about A

| | Force, N | Lever, m | Nm | Dir |
|---|---|---|---|---|
| M1 | 25.00 | 1 | 25.00 | pos |
| M2 | 43.30 | 1.2 | 51.96 | pos |
| M3 | 80.00 | 2.4 | -192.00 | neg |
| M4 | 38.35 | 3 | 115.04 | pos |
| Sum | | | 0.00 | |

By

| Sum of y-forces, N | | | Sum of x-forces, N | |
|---|---|---|---|---|
| By | 38.35 | | Fx | -43.30 |
| Fy | 25.00 | | Ax | 43.30 |
| Dy | -80.00 | | | |
| Ay | 16.65 | | | |
| Sum | 0.00 | | Sum | 0.00 |

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## Figure 1c: Increasing Force F to 200 N

## Figure 2a: Series RLC Circuit with a Generator Frequency of 60 Hz

**Series R, L &C Circuit**

where f = 60 Hz

| | | | |
|---|---|---|---|
| L = | 500 milliH = | 0.5 | H |
| XL = | 2πfL = | 188.50 ohms | |
| C = | 5 microF = | 0.000005 | F |
| Xc = | 1/2πfC= | 530.52 ohms | |
| f = | 60 Hx | | |

VLI: Voltage leads Current thru an Inductor
ICV: Current leads Voltage thru a Capacitor
Phasor Diagram:  Vector Diagram

**Total Impedance**

| | Phasor | φ,Degr | φ, Rdns | Real | Imaginary |
|---|---|---|---|---|---|
| R | 50.00 | 0 | 0 | 50.00 | 0 |
| XL | 188.50 | 90 | | 0.00 | 188.50 |
| XC | 530.52 | -90 | | 0.00 | -530.52 |
| ZT | 345.66 | -81.68 | -1.43 | 50.00 | -342.02 |

ZT = Sqrt(R^2+Xn^2)    Xn=XL+Xc

**Total Current,    I = V/ZT**

| V | ZT | IT |
|---|---|---|
| 240 | 345.66 | 0.694 |
| Volts | Ohms | Amps |

**Voltage Drops,    V= I*X**

| For | Resistor | Capactr | Inductr | |
|---|---|---|---|---|
| Ohms = | 50 | -530.52 | 188.50 | |
| I, Amps = | 0.69 | 0.69 | 0.69 | |
| Volt Drp= | 34.72 | -368.35 | 130.88 | -237.48 |
| Volts | VR | Vc | VL | Vn |

Total Voltage drops = VT =   Sqrt[VR^2 + (Vn)^2]
VT =   240 volts

**Power =    VT*I*cosΦ**

| VT | I | φ, Degr | φ, Rdns | Cos φ | Power |
|---|---|---|---|---|---|
| 240.00 | 0.69 | -81.68 | -1.43 | 0.14 | 24.10 |
| Volts | Amps | | | | Watts |

Voltage drops diagram:

## Figure 2b: Series RLC Circuit with a Generator Frequency of 400 Hz

VLI: Voltage leads Current thru an Inductor
ICV: Current leads Voltage thru a Capacitor

f = 400 Hx

Phasor Diagram:  Vector Diagram

**Total Impedance**

| | Phasor | φ,Degr | φ, Rdns | Real | Imaginary |
|---|---|---|---|---|---|
| R | 50.00 | 0 | 0 | 50.00 | 0 |
| XL | 1256.64 | 90 | | 0.00 | 1256.64 |
| XC | 79.58 | -90 | | 0.00 | -79.58 |
| ZT | 1178.12 | 87.57 | 1.53 | 50.00 | 1177.06 |

ZT = Sqrt(R^2+Xn^2)    Xn=XL+Xc

**Total Current,    I = V/ZT**

| V | ZT | IT |
|---|---|---|
| 240 | 1178.12 | 0.204 |
| Volts | Ohms | Amps |

**Voltage Drops,    V= I*X**

| For | Resistor | Capactr | Inductr | |
|---|---|---|---|---|
| Ohms = | 50 | -79.58 | 1256.64 | |
| I, Amps = | 0.20 | 0.20 | 0.20 | |
| Volt Drp= | 10.19 | -16.21 | 255.99 | 239.78 |
| Volts | VR | Vc | VL | Vn |

Total Voltage drops = VT =   Sqrt[VR^2 + (Vn)^2]
VT =   240 volts

**Power =    VT*I*cosΦ**

| VT | I | φ, Degr | φ, Rdns | Cos φ | Power |
|---|---|---|---|---|---|
| 240.00 | 0.20 | 87.57 | 1.53 | 0.04 | 2.07 |
| Volts | Amps | | | | Watts |

Voltage drops diagram:

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## Figure 3: A Partial of a Student's Test Response with a Grading Column

EGN 1002 Test #3      Fall 2017 Template

P1: Work and Power

| | | | Student Applied | Max |
|---|---|---|---|---|
| | | | 81 | 100 |

At this leg of a tour, the bicyclist must accelerate his bike from 16 km/hr to 48 km/hr over a level distance of 50 meters.

a. What work must be done over the distance traveled? Express work in Joules (J).
b. What force is being applied on the bicycle over the 50 meter distance?
c. What is the average power applied in Watts and in horsepower?

Show all units

| Bike's mass = | 18 kg | | total mass = 18+75 |
|---|---|---|---|
| Rider's mass = | 75 kg | | 93 |

| v1 = | 16 km/hr | 4.44 m/s | |
|---|---|---|---|
| | | | wt = | 9.48 |
| v2 = | 48 km/hr | 13.33 m/s | |

| level distance of travel = | | 50 meters |
|---|---|---|
| g = | 9.8 m/s | |

a. Work Done

Use the Work-Energy Equation:

?????

| Change in PE = | 8.89 m/s | |
|---|---|---|
| So, U[1>2] = ? | | KE = m*v^2/2 |

| Total mass: | mt = | 93 kg |
|---|---|---|

| | | | P1 | | |
|---|---|---|---|---|---|
| At v1 = | KE1 = | 918.52 kgm/s | | | |
| | KE1 = | 918.52 Nm | KE1 | 5 | 5 |
| At v2 = | KE2 = | 8266.67 kgm/s | | | |
| | KE2 = | 8266.67 Nm | KE2 | 5 | 5 |
| Work = U[1>2] = | 50 | 7348.15 Nm | | | |
| Work = U[1>2] = | J | 7348.15 J | Work | 0 | 5 |

## Figure 4: A Projectile Problem Showing Travel vs Time

Projectiles

Ball a is thrown downward at 10 ft/s from the top of a 60 ft tower. At the same instant, ball b is thrown up from the bottom of a pit 20 ft below ground level at a speed of 60 ft/s.

Named cell:
Hao = 60 ft

Named cell:
grav = -32.2 ft/s^2

Named cell:
Vao = -10 ft/s

Named cell:
Vbo = 60 ft/s

Named cell:
Hbo = -20 ft

To solve algebraically:
Ha =(grav*t^2)/2 + Va*t + Ho , Va = -10 ft/s & Ho = 60 ft
Va = dH/dt = grav*t + Va + 0

Hb = (grav*t^2)/2 + Vb*t + Ho, Vb = 60 ft/s & Ho = -20 ft
Vb = grav*t + Vb + 0

Set Ha = Hb and solve for t, the time the two balls would be at the same height.
Then for the time, t, solve for Ha or Hb.

V = grav*t +Vo

| t | Va | Ha | Vb | Hb | |
|---|---|---|---|---|---|
| 0.0 | -10.00 | 60.00 | 60.00 | -20.00 | |
| 0.1 | -13.22 | 58.84 | 56.78 | -14.16 | |
| 0.2 | -16.44 | 57.36 | 53.56 | -8.64 | |
| 0.3 | -19.66 | 55.55 | 50.34 | -3.45 | |
| 0.4 | -22.88 | 53.42 | 47.12 | 1.42 | |
| 0.5 | -26.10 | 50.98 | 43.90 | 5.98 | |
| 0.6 | -29.32 | 48.20 | 40.68 | 10.20 | |
| 0.7 | -32.54 | 45.11 | 37.46 | 14.11 | |
| 0.8 | -35.76 | 41.70 | 34.24 | 17.70 | |
| 0.9 | -38.98 | 37.96 | 31.02 | 20.96 | |
| 1.0 | -42.20 | 33.90 | 27.80 | 23.90 | |
| 1.1 | -45.42 | 29.52 | 24.58 | 26.52 | Height of ball A and B is the same at t=1.1 to 1.2 seconds. |
| 1.2 | -48.64 | 24.82 | 21.36 | 28.82 | |
| 1.3 | -51.86 | 19.79 | 18.14 | 30.79 | |
| 1.4 | -55.08 | 14.44 | 14.92 | 32.44 | |
| 1.5 | -58.30 | 8.77 | 11.70 | 33.78 | Ball A hits ground after 1.6 to 1.7 seconds. Velocity when it hits ground is -61.6 ft/sec. |
| 1.6 | -61.52 | 2.78 | 8.48 | 34.78 | |
| 1.7 | -64.74 | -3.53 | 5.26 | 35.47 | |
| 1.8 | | | 2.04 | 35.84 | |
| 1.9 | | | -1.18 | 35.88 | Max height of ball B = 35.85 ft |
| 2.0 | | | -4.40 | 35.60 | |
| 2.1 | | | -7.62 | 35.00 | |
| 2.2 | | | -10.84 | 34.08 | |
| 2.3 | | | -14.06 | 32.83 | |
| 2.4 | | | -17.28 | 31.26 | |
| 2.5 | | | -20.50 | 29.38 | |
| 2.6 | | | -23.72 | 27.16 | |
| 2.7 | | | -26.94 | 24.63 | |
| 2.8 | | | -30.16 | 21.78 | |
| 2.9 | | | -33.38 | 18.60 | |
| 3.0 | | | -36.60 | 15.10 | |
| 3.1 | | | -39.82 | 11.28 | |
| 3.2 | | | -43.04 | 7.14 | |
| 3.3 | | | -46.26 | 2.67 | Ball B hits ground after 3.3 seconds. Velocity when it hits ground is -46.23 ft/s. |
| 3.4 | | | -49.48 | -2.12 | |
| 3.5 | | | -52.70 | -7.23 | |

Find and highlight your answers using the given table format.

a  The time ball a and ball b reach the same height.
b  The height when ball a and ball b are at the same height
c  The maximum height that ball b will reach.
d  The time it will take for ball a to hit the ground.
e  The velocity of ball a when it hits the ground.
f  The time it takes for ball b to hit the ground.
g  The velocity of ball b when it hits the ground.

## Figure 5: A Histogram Problem Showing Charting Features
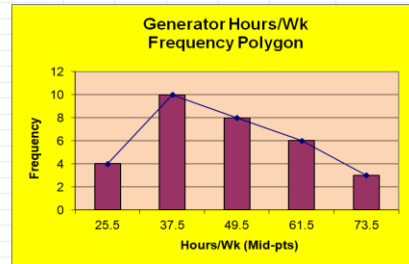
Histogram

| | Given Hrs/wk | | Sorted Hrs/wk |
|---|---|---|---|
| 1 | 20 | 1 | 20 |
| 2 | 75 | 2 | 26 |
| 3 | 43 | 3 | 28 |
| 4 | 62 | 4 | 29 |
| 5 | 51 | 1 | 32 |
| 6 | 52 | 2 | 33 |
| 7 | 78 | 3 | 36 |
| 8 | 33 | 4 | 37 |
| 9 | 28 | 5 | 39 |
| 10 | 39 | 6 | 40 |
| 11 | 61 | 7 | 41 |
| 12 | 56 | 8 | 42 |
| 13 | 43 | 9 | 43 |
| 14 | 49 | 10 | 43 |
| 15 | 48 | 1 | 46 |
| 16 | 49 | 2 | 48 |
| 17 | 71 | 3 | 49 |
| 18 | 53 | 4 | 49 |
| 19 | 57 | 5 | 51 |
| 20 | 46 | 6 | 51 |
| 21 | 42 | 7 | 52 |
| 22 | 41 | 8 | 53 |
| 23 | 63 | 1 | 56 |
| 24 | 36 | 2 | 57 |
| 25 | 51 | 3 | 59 |
| 26 | 59 | 4 | 61 |
| 27 | 40 | 5 | 62 |
| 28 | 32 | 6 | 63 |
| 29 | 37 | 7 | 71 |
| 30 | 29 | 8 | 75 |
| 31 | 26 | 9 | 78 |

| Range = | 58 | |
|---|---|---|
| Categories= | | 5 |
| Cat size = | 11.6 | |
| Cat size, rnded= | 12 | |

| Cat Boundaries | | Freq | Mid-pt | Freq | Cum Freq | Cum Freq % |
|---|---|---|---|---|---|---|
| 19.5 | 31.5 | 4 | 25.5 | 4 | 4.0 | 12.9% |
| 31.5 | 43.5 | 10 | 37.5 | 10 | 14.0 | 45.2% |
| 43.5 | 55.5 | 8 | 49.5 | 8 | 22.0 | 71.0% |
| 55.5 | 67.5 | 6 | 61.5 | 6 | 28.0 | 90.3% |
| 67.5 | 79.5 | 3 | 73.5 | 3 | 31.0 | 100.0% |
| Totals | | 31 | | | | |

Generator Hours/Wk Frequency Polygon

Generator Hours/ Week Cumulative Frequency

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