Graphical Data Presentation Techniques for Freshmen

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Abstract

First-semester freshmen may have learned how to produce pie charts and bar graphs in high school, but they have little experience with engineering graphs. To become successful engineers, students need to develop skills in presenting and interpreting graphical data. An introductory materials course is an ideal place to introduce these concepts because the topic is data-rich, and successful interpretation of graphs leads to understanding of materials engineering and economic concepts. For example, the shape of the liquidus curve on the iron-carbon phase diagram helps explain why cast steels are more expensive to manufacture than cast irons.

In this course, students develop graphical skills from lectures, handouts, and assignments. For example, students plot their own hardness readings together with an empirically-derived ASTM curve, then they evaluate how well their data matches the curve. They create phase diagrams from alloy data. They create stress-strain diagrams from their own laboratory readings, and calculate mechanical properties from the results. They learn how to deal with outliers on a homework assignment. They learn that Microsoft Excel's built-in curve-fitting choices do not cover unusual data patterns, such as the S-curves for impact vs. temperature graphs.

Student performance is assessed with a grading rubric which evaluates graphs within laboratory reports. Low performance on three laboratory reports has led to instructional improvements, including additional focus in the lecture and detailed handouts. Subsequent assessment shows continued improvement in skill levels from one laboratory report to the next, and from one semester to the next.

Introduction

TAC/ABET requires that engineering technology graduates have an ability to communicate effectively (Criterion 3, Program Outcome g).[1] The MET program at IPFW includes two communications courses and three English courses which develop students' skills in public speaking and technical writing. However, these courses alone do not completely satisfy the TAC/ABET communication criterion; in addition, students need graphical literacy. Learning to create and interpret engineering graphs helps to complete this requirement.

When I started teaching freshman materials classes for MET students, I found that the level of graphical literacy was low. Students did not understand the language of graphs, and many students mistakenly used MS Excel "line" graphs (which are really bar charts) rather than x-y scatter graphs to show relationships between variables. In response, I developed a set of graphical literacy outcomes. By the end of the course, students should be able to:

- create x-y scatter graphs
- understand what plotting “A vs. B” means
- understand dependent & independent variables
- display lab data and an empirically-derived curve on the same graph
- use regression routines
- report outliers
- display small data sets (3 data points)
- compare multiple data sets
- draw freehand curves when regression routines are unavailable

In the first semester, I introduced a general handout which explains how to create engineering graphs. Poor performance on subsequent graphing assignments showed that few students paid attention to the handout. Instead, students responded better to instructions that were assignment-specific. Therefore, I started to add handouts and lecture discussion points for each lab experiment, emphasizing key points needed for each assignment. Table 1 summarizes the timeline of teaching of graphing skills to 122 students in twelve materials classes over nine semesters. The following discussion explains these improvements in more detail.

Semester	**Class size**	**Improvement**
S04	10	New laboratory manual and guide for creating graphs for lab reports.
F04	–	
S05	9	
F05	11	Rockwell vs. Brinell diagram in lab manual.
S06	8	Rubric for grading lab reports.
F06	15	Handout explaining how to set up the spreadsheet for tensile test results & graphs. PowerPoint presentation on drawing S-curves in Excel.
S07	12 & 15	ASTM curve added to Rockwell vs. Brinell cartoon in lab manual. Handout explaining how to set up the spreadsheet for the Rockwell vs. Brinell graph.
F07	13	
S08	11 & 18	HW assignment to produce a phase diagram from a table of phase/temperature data.
F08	5 & 12	

Table 1: Class sizes and improvements in teaching graphing skills as a function of semester. There were two sections of this class in Spring 2007, Spring 2008, and Fall 2008.

Hardness Test

In the first laboratory experiment, students measure Rockwell B and Brinell hardness of three steel samples, a brass sample, and an aluminum sample. Students are asked to plot Rockwell hardness vs. Brinell hardness, along with this empirically-derived equation for steels:[ii]

$$HRB = 114.665 + 0.0882795(HB) - 0.000141855(HB^2) - 6695.28(HB^{-1})$$

Although these students learned to produce graphs using MS Excel in a prior course, many students do not understand graphing terminology. For example, when asked to plot variable "A" vs. variable "B", students are uncertain which axis to use for each variable. In Fall 2005, I added Figure 1 to the lab manual to help students plot the data as requested. However, many students misunderstood the instructions for plotting the ASTM equation, and instead used Excel's curve-fitting routines to draw a second-order least-squares line through the data. Some students plotted the ASTM curve on a separate graph, making it difficult to compare the data with the curve. In Spring 2007, I changed the diagram in the lab manual to Figure 2.

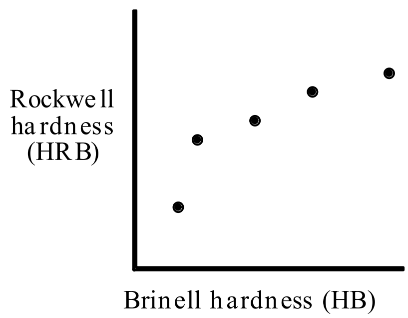


Figure 1: Diagram of a hardness plot from the Fall 2005 laboratory manual.

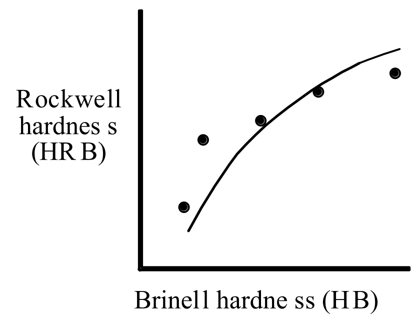


Figure 2: Improved diagram of a hardness plot from the Spring 2007 laboratory manual, showing the ASTM least-squares curve.

This diagram helps students visualize the end product, but not the means to produce it, so I also introduced a handout which shows how to set up the spreadsheet, and how to create the graph, as shown in Figure 3. After I introduced this handout, I found that student success was strongly linked to attendance at the lecture where we discussed this handout. In general, students who miss this lecture are unlikely to graph the ASTM curve correctly, even if they pick up the handout later.

Torsion Test

In the second lab experiment, students twist steel, brass, and aluminum rods elastically, and measure the angle of twist produced by various torques. Students plot the angle of twist vs. the applied torque, determine the slope of the line, and use the torque equation given in the lab manual to calculate the shear modulus of each material. This equation is presented as:

$$\theta = \frac{TL}{GJ}$$

where θ = angle of twist, T = torque, L = rod length, J = polar moment of inertia, and G = shear modulus. Students rewrite the equation as:

$$G = \frac{L}{J(\theta/T)}$$

In the lab, you will collect four Brinell hardness readings and four more Rockwell hardness readings on each of five metal samples: aluminum, brass, and three steel samples.

Sample	Brinell (HB)	Rockwell (HRB)
Steel 1	229, 217, 217, 223	99, 93, 96, 92
Steel 2	131, 128, 134, 128	78, 71, 74, 73
Steel 3	163, 156, 156, 159	83, 89, 84, 81
Aluminum	149, 153, 157, 153	91, 81, 85, 83
Brass	119, 109, 114, 111	68, 67, 67, 69

Next, calculate the average hardness for each set of readings.

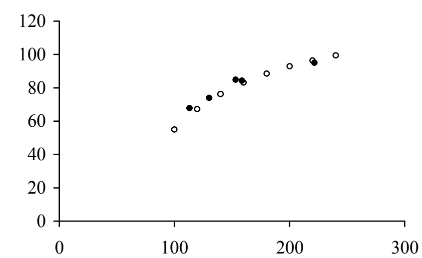
Sample	Brinell (HB)	Rockwell (HRB)
Steel 1	221.5	95.0
Steel 2	130.3	74.0
Steel 3	158.5	84.3
Aluminum	153.0	85.0
Brass	113.3	67.8

You are going to plot the average Rockwell hardness readings vs. average Brinell hardness readings, along with the least-squares equation from ASTM Standard E140 for irons and steels. This equation is given in the lab manual.

Make up some Brinell hardness numbers that cover the range of experimental data, then use the ASTM equation to calculate the equivalent Rockwell hardness. The Rockwell numbers go in a new column, to the far right (in place of the xxx values).

Sample	Brinell (HB)	Rockwell (HRB)	HRB calc.
Steel 1	221.5	95.0	
Steel 2	130.3	74.0	
Steel 3	158.5	84.3	
Aluminum	153.0	85.0	
Brass	113.3	67.8	
100			xxx
120			xxx
140			xxx
160			xxx
180			xxx
200			xxx
220			xxx
240			xxx

Select the three columns of numbers, and create an x-y plot. The lab data shows up as five black circles, and the calculated values show up as white circles on this graph.



In science and engineering graphs, data appears as points; theory appears as lines.
This version of the graph shows the theory as a line, and includes axis labels. The origin does not have to be at (0, 0)…here, it's at (100, 50) so the graph is easier to interpret.
The equation fits the lab data pretty well.
The graph could be improved by labeling the data points according to their materials.

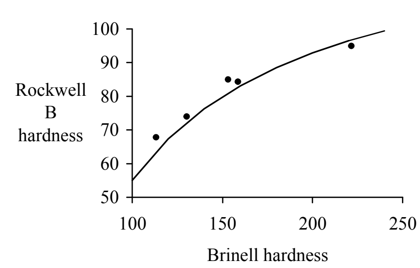


Figure 3: Handout which explains how to create the hardness graph.

where θ/T is the slope. Students calculate shear modulus for each material, then compare the results with published values. In class, we discuss the scientific convention of plotting the dependent variable on the vertical axis, and the independent variable on the horizontal axis.

In this experiment, each material has three data points, so students learn how to present small data sets. In theory, the data points should align. However, if the torsion rod slips in the clamps, if the dial indicator is not read correctly, or if the apparatus is bumped, then the points may not align. In Figure 4, the clamps may have slipped on the brass sample at the high torque reading. Some students add a datapoint at the origin to extend the dataset to four points per sample.

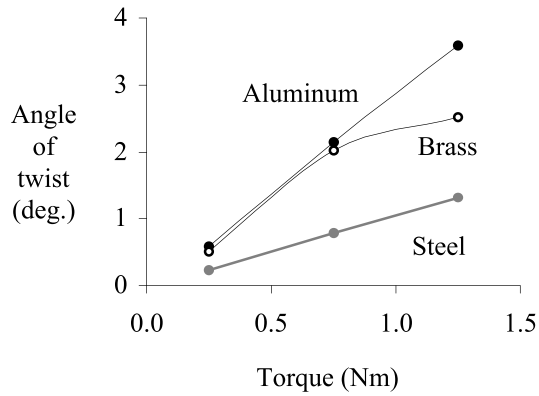


Figure 4: Torsion test results from a recent semester. Lines simply connect the dots. The brass line suggests that the clamps slipped at the high torque reading, so the slope of the "good data" (first two points) is similar to aluminum.

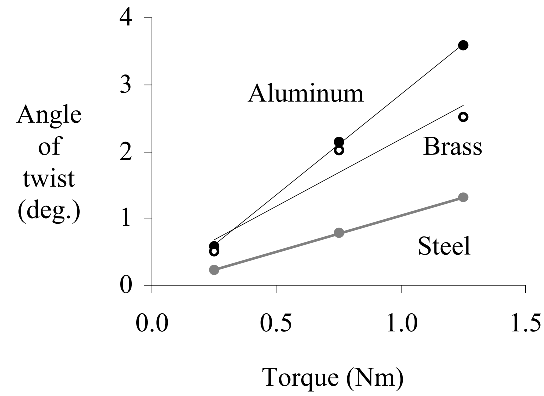


Figure 5: Data from Figure 4. Straight-line linear regression lines suggest that the middle reading for brass is high, and that the slope is less than aluminum, which is consistent with published values of shear modulus.

A common error in the first few semesters was to reverse the two axes. The lab manual instructs students to "plot the angle of twist vs. the applied torque for each rod, and discuss the results." This error was less common after Fall 2005, when Figure 1 was added to the hardness test in the lab manual. Once students learn "A vs. B" terminology in lab #1, they know it for lab #2.

Tensile Test

The third lab experiment is a tensile test of two materials. Students work as a team to run the test (ABET criterion "e"). One student reads an extensometer strapped to the specimen, a second reads a dial indicator which measures crosshead movement, a third reads the force gauge, a fourth operates the machine, and a fifth transcribes the data.

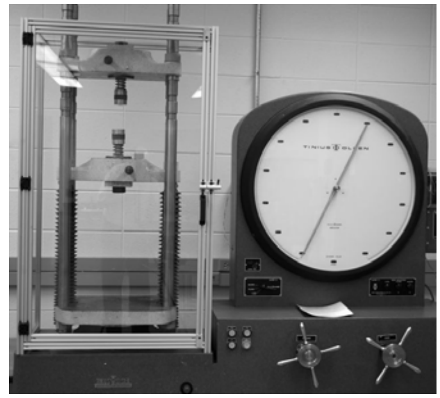


Figure 6: Old-style hydraulic tensile testing machine.

While the hardness and torsion tests produce a handful of data points, the tensile test produces between 45 and 60 readings per sample. This large dataset introduces the opportunity for transcription error, so students must decide what to do if a number seems wrong. Did the extensometer slip, did the gauge reader misread the value, or did the scribe write it down incorrectly?

This experiment requires more data processing than any other in the course. Students must calibrate the dial indicator readings to the extensometer readings, because thread seating influences the initial dial indicator readings. Students calculate engineering strain from extensometer and dial indicator readings, and engineering stress from force readings. Next, they determine yield strength, ultimate tensile strength, rupture strength, and Young's modulus.

Up to Spring 2006, many students struggled to produce stress/strain curves from the data. Common errors included using elongation in place of strain; calculating stress incorrectly; and failing to adjust the dial indicator readings. In Fall 2006 I introduced a 4-page handout describing how to process the raw data from the tensile test (Figures 7 through 10). Data tables appear on the left side of each page, while instructions appear at the right. Students receive this handout in class, two days before running the test. We discuss each table and the instructions for calculating stress and strain. We also discuss how to graph the results, how to determine Young's modulus using linear regression.

As with the hardness test, attendance in the lecture correlated with graphing success. Students who attended the lecture when the handout was discussed were much more likely to be able to produce good stress-strain curves.

Extensometer readings (0.0001")	Dial indicator readings (0.001")	Force (lb.)
5	6	500
10	10	900
15	13	1,350
20	15	1,750
25	17	2,150
30	19	2,250
35	21	3,000
40	23	3,400
45	25	3,750
50	26	4,200
55	26	4,500
60	27	4,800
65	28	5,250
	40	7,700
	50	9,750
	60	10,100
	70	10,300
	80	10,450
	100	10,550
	120	10,750
	140	10,800
	160	10,850
	185	11,000
	220	11,000
	260	11,000
	300	11,050
	340	11,050
	380	10,750
	420	10,500
	460	10,000
	500	9,250

Data Processing

In the lab, you'll collect data from 3 instruments.

The **extensometer** is clipped to the test specimen; it measures the change in length in increments of 0.0001". However, its range is too small to measure the change in length during plastic deformation, and it could be damaged when the specimen breaks, so the extensometer is removed once the specimen starts to permanently deform.

The **dial indicator** measures the change in distance between the two crossheads. The specimen is threaded into nuts supported by the crossheads. At the start of the test, while the threads are being seated, the dial indicator readings include seating *and* specimen stretching. Therefore, the initial readings are not useful.

Force is read off the large **force dial**, in pounds.

The test runs pretty fast. There will not be enough time to write all the zeroes in the extensometer and dial indicator readings, so the data sheet should look like the columns at the left.

Extensometer readings (0.0001")	Dial indicator readings (0.001")	Extensometer readings (in.)	Dial indicator readings (in.)
5	6	0.0005	
10	10	0.0010	
15	13	0.0015	
20	15	0.0020	
25	17	0.0025	
30	19	0.0030	
35	21	0.0035	
40	23	0.0040	
45	25	0.0045	
50	26	0.0050	
55	26	0.0055	
60	27	0.0060	
65	28	0.0065	0.0280
	40		0.0400
	50		0.0500
	60		0.0600
	70		0.0700
	80		0.0800
	100		0.1000
	120		0.1200
	140		0.1400
	160		0.1600
	185		0.1850
	220		0.2200
	260		0.2600
	300		0.3000
	340		0.3400
	380		0.3800
	420		0.4200
	460		0.4600
	500		0.5000

Processing the data is easiest in a spreadsheet program, like MS Excel. Divide the extensometer readings by 10000, and the dial indicator readings by 1000, to get readings in inches.

We won't use the dial indicator readings that are taken before the extensometer is removed, so the first dozen dial indicator readings on this table are left blank.

Figure 7: Tensile test handout (page 1 of 4). This page shows how to set up the raw data, and how to convert extensometer and crosshead readings to inches.

Extenso-meter readings (0.0001")	Dial indicator readings (0.001")	Extenso-meter readings (in.)	Dial indicator readings (in.)	Adjusted dial indicator readings (in.)
5	6	0.0005		
10	10	0.0010		
15	13	0.0015		
20	15	0.0020		
25	17	0.0025		
30	19	0.0030		
35	21	0.0035		
40	23	0.0040		
45	25	0.0045		
50	26	0.0050		
55	26	0.0055		
60	27	0.0060		
65	28	0.0065	0.0280	0.0065
	40		0.0400	0.0185
	50		0.0500	0.0285
	60		0.0600	0.0385
	70		0.0700	0.0485
	80		0.0800	0.0585
	100		0.1000	0.0785
	120		0.1200	0.0985
	140		0.1400	0.1185
	160		0.1600	0.1385
	185		0.1850	0.1635
	220		0.2200	0.1985
	260		0.2600	0.2385
	300		0.3000	0.2785
	340		0.3400	0.3185
	380		0.3800	0.3585
	420		0.4200	0.3985
	460		0.4600	0.4385
	500		0.5000	0.4785

Since the dial indicator measures extension *and* thread seating at the beginning of the test, we need to adjust the readings to match the extensometer readings. Take the difference between the last extensometer reading and the corresponding dial indicator reading, in this case:

0.0280" – 0.0065" = 0.0215"

Subtract this value from the dial indicator readings to get "adjusted" dial indicator readings. In effect, you are calibrating the dial indicator.

For example, the first few "adjusted" dial indicator readings are:

0.0280" – 0.0215" = 0.0065"
0.0400" – 0.0215" = 0.0185"
0.0500" – 0.0215" = 0.0285"
0.0600" – 0.0215" = 0.0385"

Extenso-meter readings (0.0001")	Dial indicator readings (0.001")	Extenso-meter readings (in.)	Dial indicator readings (in.)	Adjusted dial indicator readings (in.)	Change in length (in.)	Strain
5	6	0.0005			0.0005	0.00025
10	10	0.0010			0.0010	0.00050
15	13	0.0015			0.0015	0.00075
20	15	0.0020			0.0020	0.00100
25	17	0.0025			0.0025	0.00125
30	19	0.0030			0.0030	0.00150
35	21	0.0035			0.0035	0.00175
40	23	0.0040			0.0040	0.00200
45	25	0.0045			0.0045	0.00225
50	26	0.0050			0.0050	0.00250
55	26	0.0055			0.0055	0.00275
60	27	0.0060			0.0060	0.00300
65	28	0.0065	0.0280	0.0065	0.0065	0.00325
	40		0.0400	0.0185	0.0185	0.00925
	50		0.0500	0.0285	0.0285	0.01425
	60		0.0600	0.0385	0.0385	0.01925
	70		0.0700	0.0485	0.0485	0.02425
	80		0.0800	0.0585	0.0585	0.02925
	100		0.1000	0.0785	0.0785	0.03925
	120		0.1200	0.0985	0.0985	0.04925
	140		0.1400	0.1185	0.1185	0.05925
	160		0.1600	0.1385	0.1385	0.06925
	185		0.1850	0.1635	0.1635	0.08175
	220		0.2200	0.1985	0.1985	0.09925
	260		0.2600	0.2385	0.2385	0.11925
	300		0.3000	0.2785	0.2785	0.13925
	340		0.3400	0.3185	0.3185	0.15925
	380		0.3800	0.3585	0.3585	0.17925
	420		0.4200	0.3985	0.3985	0.19925
	460		0.4600	0.4385	0.4385	0.21925
	500		0.5000	0.4785	0.4785	0.23925

The change in length column includes all the extensometer readings, and the subsequent adjusted dial indicator readings.

Strain is the change in length divided by the initial gauge length of 2 inches. For example:

0.0005" ÷ 2" = 0.00025
0.0010" ÷ 2" = 0.00050
0.0015" ÷ 2" = 0.00075

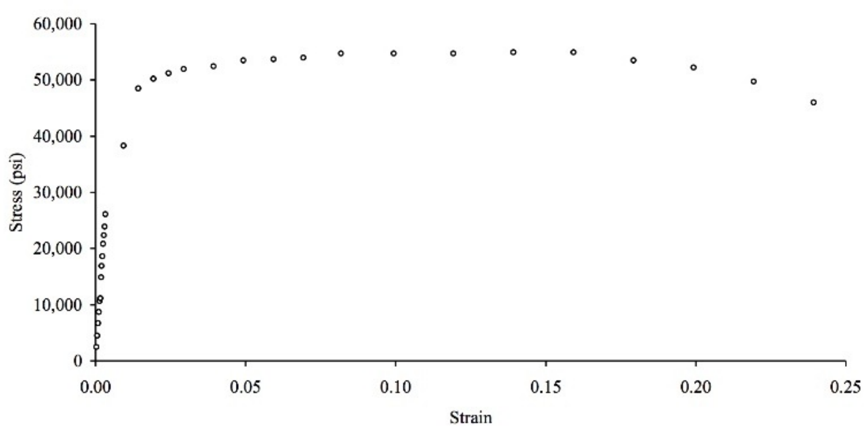
Strain has no units.

Figure 8: Tensile test handout (page 2 of 4). This page shows how to calibrate crosshead readings to extensometer readings, and how to calculate strain.

Extenso-meter readings (0.0001")	Dial indicator readings (0.001")	Extenso-meter readings (in.)	Dial indicator readings (in.)	Adjusted dial indicator readings (in.)	Change in length (in.)	Strain	Force (lb.)	Stress (psi)
5	6	0.0005			0.0005	0.00025	500	2,486
10	10	0.0010			0.0010	0.00050	900	4,476
15	13	0.0015			0.0015	0.00075	1,350	6,713
20	15	0.0020			0.0020	0.00100	1,750	8,703
25	17	0.0025			0.0025	0.00125	2,150	10,692
30	19	0.0030			0.0030	0.00150	2,250	11,189
35	21	0.0035			0.0035	0.00175	3,000	14,919
40	23	0.0040			0.0040	0.00200	3,400	16,908
45	25	0.0045			0.0045	0.00225	3,750	18,648
50	26	0.0050			0.0050	0.00250	4,200	20,886
55	26	0.0055			0.0055	0.00275	4,500	22,378
60	27	0.0060			0.0060	0.00300	4,800	23,870
65	28	0.0065	0.0280	0.0065	0.0065	0.00325	5,250	26,108
	40		0.0400	0.0185	0.0185	0.00925	7,700	38,291
	50		0.0500	0.0285	0.0285	0.01425	9,750	48,486
	60		0.0600	0.0385	0.0385	0.01925	10,100	50,226
	70		0.0700	0.0485	0.0485	0.02425	10,300	51,221
	80		0.0800	0.0585	0.0585	0.02925	10,450	51,967
	100		0.1000	0.0785	0.0785	0.03925	10,550	52,464
	120		0.1200	0.0985	0.0985	0.04925	10,750	53,459
	140		0.1400	0.1185	0.1185	0.05925	10,800	53,707
	160		0.1600	0.1385	0.1385	0.06925	10,850	53,956
	185		0.1850	0.1635	0.1635	0.08175	11,000	54,702
	220		0.2200	0.1985	0.1985	0.09925	11,000	54,702
	260		0.2600	0.2385	0.2385	0.11925	11,000	54,702
	300		0.3000	0.2785	0.2785	0.13925	11,050	54,950
	340		0.3400	0.3185	0.3185	0.15925	11,050	54,950
	380		0.3800	0.3585	0.3585	0.17925	10,750	53,459
	420		0.4200	0.3985	0.3985	0.19925	10,500	52,215
	460		0.4600	0.4385	0.4385	0.21925	10,000	49,729
	500		0.5000	0.4785	0.4785	0.23925	9,250	45,999

Divide the force by the initial cross-sectional area of the specimen to get tensile stress. This sample had an initial diameter of 0.506", so its cross-sectional area is
$\frac{1}{4} \pi (0.506 \text{ in.})^2$
$= 0.2011 \text{ in}^2$.

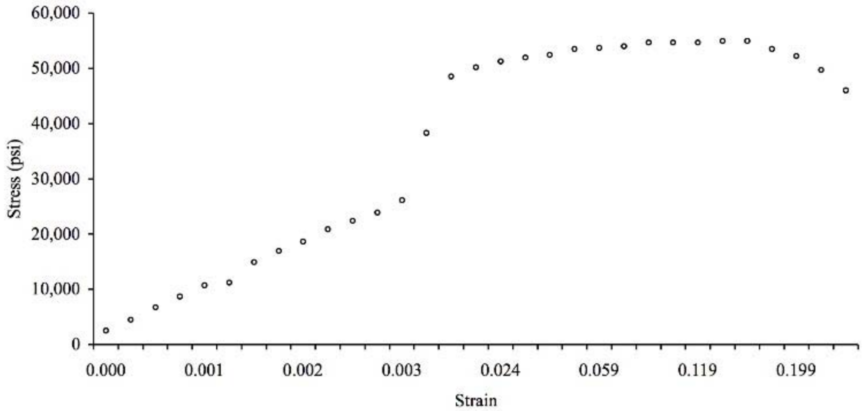
Next, create a stress-strain curve, using the data outlined in the boxes.



Use an x-y graph to show the data.

Be sure to show the data points. You may connect the dots if it helps to tell the story…but don't show a line without data points!

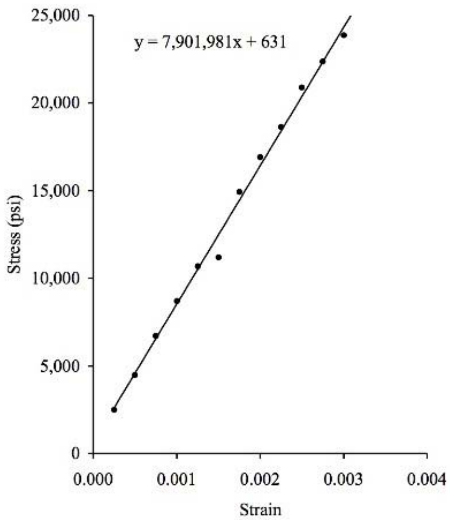
Figure 9: Tensile test handout (page 3 of 4). This page shows how to plot stress vs. strain using an x-y scatter plot.



If you use a line graph by mistake, the data will look like this.

The line graph spaces the x values at uniform intervals. Each reading corresponds to a space between tick marks.

A line graph cannot show the relationship between two variables.



Young's modulus is the slope of the elastic portion of the stress-strain curve. One way to find it is to plot only the elastic stress/strain data on an x-y graph, and use linear regression (select **Add Trendline** from the chart menu in MS Excel). This graph uses only the first 12 data points…after that, the material permanently deforms. Under **Options**, display the equation, then change the number format if needed.

In this example, Young's modulus is 7.9 million psi. The line is a really great fit…this gives us confidence that the elastic deformation of this specimen is truly linear.

The intercept value indicates that there was a small preload at the beginning of the test. The preload was 631 psi × 0.2011 in.^{2} = 127 lb.

Figure 10: Tensile test handout (page 4 of 4). This page explains why the MS Excel "line graph" is inappropriate, and it shows how to find Young's modulus.

Impact Test

The final lab test produces more scatter than any other test. Students break three steel alloys at six temperatures (two specimens of each alloy at each temperature, or 36 data points). Because MS Excel is designed for business applications, not science and engineering, the menu of curve-fitting shapes (or "trendlines" in Excel) does not include S-curves for impact tests, creep tests, etc. Instead, students must use Excel's drawing tool to create S-curves on their graphs.

Up until Spring 2006, many students attempted to use nonlinear regression routines in MS Excel to draw S-curves. Students would try second- and third-order polynomials, with little success. In Fall 2006, I added PowerPoint slides to the lecture which show the various regression lines available in Excel, superimposed on impact test data. Students learn that none of the routines fit the data, and we discuss how to use the freehand drawing tool to draw S-curves.

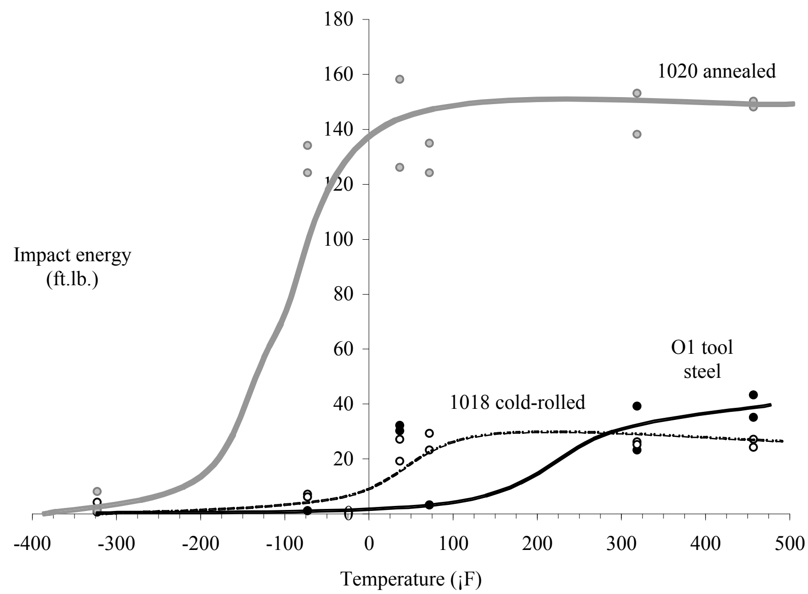


Figure 11: Typical results from an impact test of three materials. O-1 tool steel shows the strangest behavior: impact energy around 35 ft.lb. in icewater, and below 5 ft.lb. at room temperature. Students learn that samples are sometimes mislabeled.

As in previous labs, students who attend the lecture are more likely to produce good S-curves than students who skip the lecture. In this case, there is no handout to rely on. Students who hand-draw the S-curve get no credit for the curve; it must be done using software.

Homework Assignments

Lab experiments often create outliers, such as the O-1 tool steel in Figure 11. Another source of outliers is the internet. In one assignment, students collect the linear coefficients of expansion and melting points of 11 metallic elements from internet sites, then they plot the results.[iii] Student graphs typically look like the left side of Figure 12, where the outlier is magnesium. Many websites list the coefficient of thermal expansion at around 8 mm/mm/°C, which is one third of its actual value. The graph should look like the right side of Figure 12.

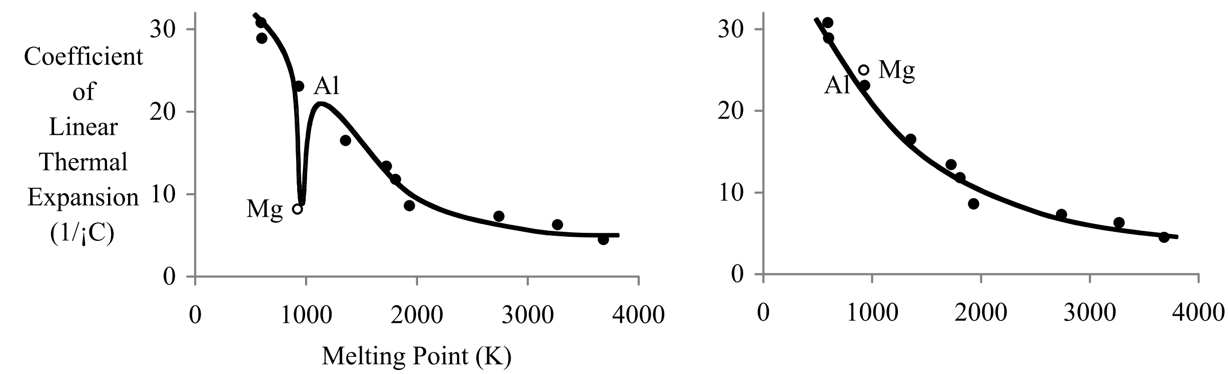


Figure 12: At left, a typical student homework submission shows magnesium substantially below the trendline. Many students draw a line passing through the magnesium point. When the correct value of magnesium is used (right), the trendline passes near all points.

In class, we compare the two graphs, and discuss errors on websites. Students learn that this type of error is hard to detect in a table, but easy to detect in a graph. They learn to use graphs as tools for critical thinking.

Most of the graphs presented in the lecture, assigned in the lab reports, or assigned in homework problems are x-y scatter graphs, generally with a dependent variable plotted as a function of an independent variable. Phase diagrams are different for two reasons: first, the dependent variable (the phase) does not appear on either axis; and second, phase diagrams cannot be plotted easily in MS Excel. In the assignment, students are given compositions, temperatures, and phases as in Table 2. They are asked to draw a eutectic phase diagram by hand as in Figure 13, then estimate the eutectic temperature and composition.

T (°C)	**%A**	**Phases**	**T (°C)**	**%A**	**Phases**	**T (°C)**	**%A**	**Phases**	**T (°C)**	**%A**	**Phases**
40	5	α	125	5	α	135	5	α	200	2	α
40	12	α+β	125	15	α	135	15	α	200	8	α+L
40	50	α+β	125	22	α+β	135	18	α+L	200	20	L
40	85	α+β	125	50	α+β	135	40	α+L	200	50	L
40	92	β	125	75	α+β	135	55	L	200	75	L
			125	80	β	135	60	β+L	200	82	β+L
						135	75	β+L	200	95	β
						135	80	β			

Table 2: Data for the phase diagram homework assignment.

I assign this problem to show students that the lines on a phase diagram may be inaccurate if the diagram is based on limited data.

Homework is due once a week, and at least one graphing assignment is included. In each case, I ask students to plot materials properties, and to explain what they have learned from the graph. In this way, students learn that graph interpretation is at least as important as graph creation. The interpretation is reinforced by class discussion when I return the graded assignments.

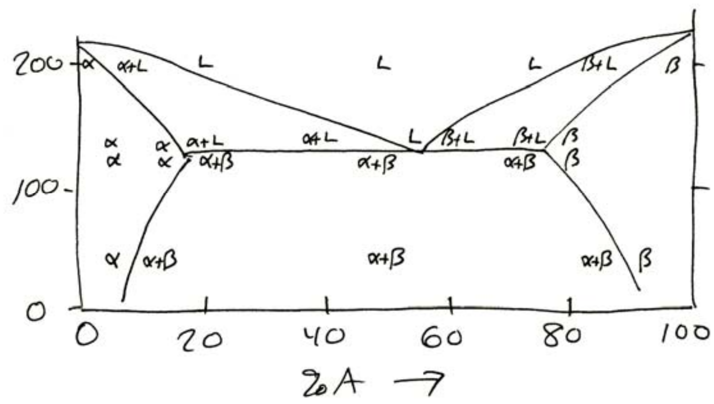


Figure 13: Typical hand-drawn phase diagram created from the data in Table 2.

Assessment

In the most recent five semesters, I used a formal rubric to grade the major parts of the lab reports, including the graphs. Students received full credit for a correctly-drawn graph; partial credit for minor errors; and no credit for major errors. In this time, the average grade on the graph portion of the laboratory reports generally increased, as shown in Figure 14. The sawtooth pattern represents a variation in the type of student enrolling from one semester to the next. Generally, older students who are employed in technical jobs have more advanced graphing skills. When a class is offered in the evening, the proportion of older to younger students increases, changing the average grades on this part of the report.

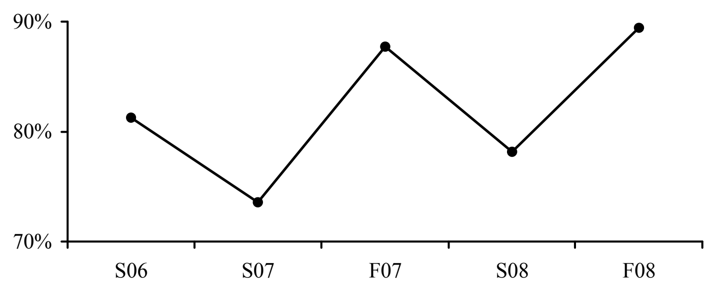


Figure 14: Average graph grade for all laboratory experiments as a function of semester.

The average grades received on the graph portion of each lab report are shown in Figure 15. For each of the three semesters shown, students became more proficient at making graphs as the semester progressed. Lab #3 contains the most difficult graphing assignment, and in every semester, graphing skills developed in the first two lab reports led to higher performance on Lab #3. Only three semesters are presented because the rubric was only recently applied to all four lab reports.

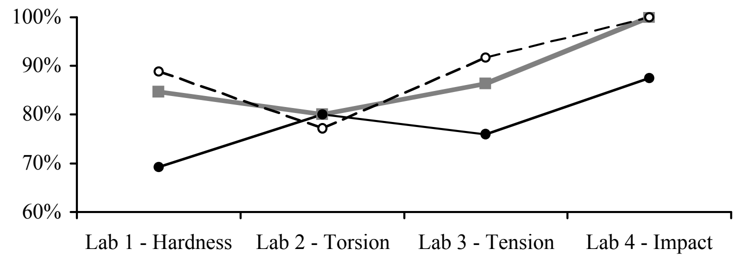


Figure 15: Student grades for creating graphs in four laboratory experiments. Each point represents the average of the graph grade for each lab report; each line represents one semester (F07 in gray squares, S08 in black circles, and F08 in hollow circles).

Conclusions

Sales and marketing professionals use a "rule of seven" to explain customer behavior. Under this rule, it takes an average of seven contacts with the customer before the sale is made. Salespeople who stop at one or two contacts are generally not successful. A similar rule applies to students; they learn by repeated exposure to ideas as well as repeated practice. If we want students to become proficient at presenting engineering data clearly and correctly in graphical form, they must see it in lectures and textbooks, and they must practice it in homework assignments and lab reports. It is not enough to present students with a single handout at the beginning of the semester, explaining how to set up engineering graphs. It is not enough to show students a single instructional video, or to assign a single graphing problem. Detailed instructions for each assignment, discussions in class, and discussions during the lab sessions all contribute to a positive result.

While the examples presented here are drawn from a freshman Materials class, the ideas and techniques can be applied to any introductory technical course in which students plot experimental data. In the hardness test, students plot data along with an experimentally-determined curve; the analogue in an engine or electric motor class would be to plot torque and speed data of a motor along with the manufacturer's curve. In the torque test, the data set is limited due to the number of available weights; the analogue in a civil materials course could be concrete compression strength as a function of water content, because time and/or cost limit the number of samples and tests. In the impact test, students must draw lines through scattered data which do not fall neatly into a preprogrammed regression pattern; the analogue in an electrical course is magnetic hysteresis loops.

Students in my Materials class see me again in Fluid Power. In this course, students create graphs for several lab reports. In the future I plan to use graph grades from both courses to determine how well students retain their graphing skills over time.

[i] 2008-2009 Criteria for Accrediting Engineering Technology Programs, TAC/ABET, Nov. 2007, p. 2.
[ii] ASTM Standard E 140-07, "Standard Hardness Conversion Tables for Metals: Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness", ASTM Book of Standards Vol. 03.01, ASTM, 2007.
[iii] Barry Dupen, "Using Internet Sources to Solve Materials Homework Assignments", 2008 ASEE Conference & Exposition, June 2008. Conference proceedings, session 3164.

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