How to Use Graphical Data Presentation Techniques to Improve Student Success, Curriculum, and Program Assessment

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Abstract

In the second half of the 20th century, quality systems used in manufacturing and service industries changed from measuring inputs to measuring outputs. ABET made this transition in 1997, changing from a focus on inputs (courses taught by professors) to measuring outputs (skills and knowledge gained and retained by students). Students, professors, program coordinators, and department chairs must answer three questions: [1] what are we doing well, [2] what are we *not* doing well, and [3] how do we improve? In some cases, we can use graphical data presentation techniques to answer these questions. Scatter graphs show relationships between variables that are not evident in tables, and they show changes in variables with respect to time. A student may ask "why is my grade lower than I would like?" We can use graphs to show the student's progress in real time as the semester advances, then predict the final course grade based on alternate hypotheses (e.g., "I will earn 90% on all remaining assignments"; "I will barely pass the remaining assignments"). As a professor, I asked why the failure rate in *Strength of Materials* is so high, then used a variety of graphs to determine the indicators for success and failure. As a consequence, my department made a curriculum change in Fall 2014; we should see results starting in Fall 2015.

This paper shows how I used graphical data presentation techniques in undergraduate Mechanical Engineering Technology classes to improve student success, teaching effectiveness, and curriculum. A nearly identical paper will be presented at the ASEE national conference in Seattle this summer.

Introduction

I spent much of the 1990s working in the automotive industry as a materials engineer and engineering manager. During that time, my employer made the transition from one quality system to another, requiring additional data collection and analysis. Automotive quality systems are based on quality management systems developed in the mid 20th century by the British Standards Institute and the US military; they focus on outcomes and continuous improvement. These quality systems became models for ABET's EC2000 criteria in 1997, as ABET changed from its 70-year practice of measuring inputs to measuring outputs. Any successful continuous improvement process links outcomes with root causes; this linkage is not always obvious. Educators can use data presentation techniques to identify these links, and then improve courses and curricula. We can also use these presentation techniques to help students identify links, so students can improve their education strategies.

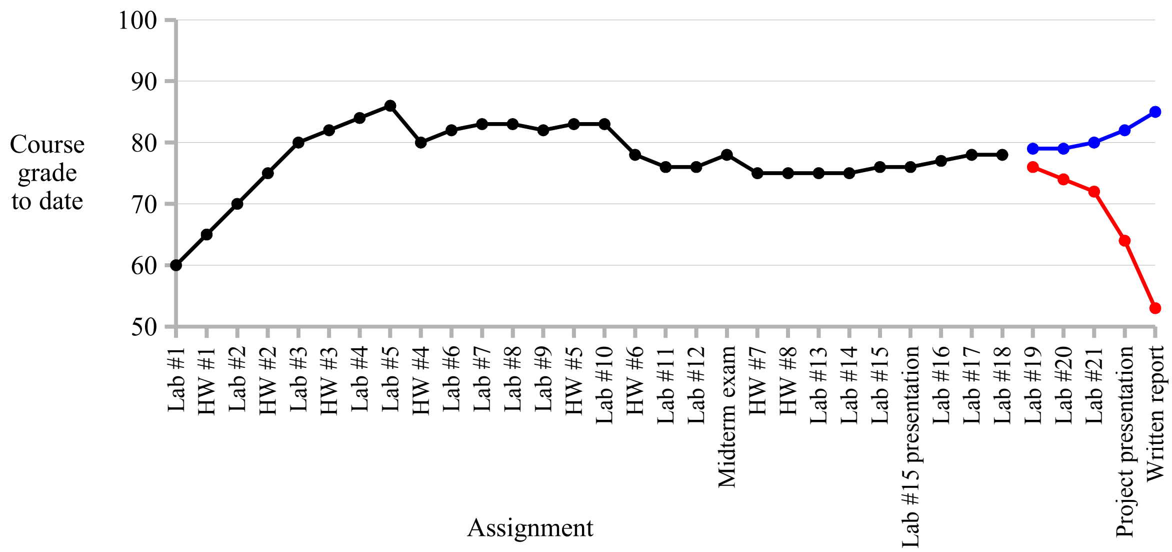
Student Success over a Semester

Students tend to have only an instantaneous awareness of grades; they see a marked grade on a returned homework assignment or exam, or a cumulative course grade in course management software, but they often have no real sense of how their course grades change over time. They also have little understanding of the effect of a zero grade on a course average. In a freshman *Introduction to Engineering Technology* course that teaches spreadsheet skills, I ask students to plot their current course grades as a function of time. The current grade is the sum of the student's earned points to date, divided by the sum of the point values of those assignments.

This grade-plotting assignment occurs towards the end of the semester, when only half a dozen assignments and projects remain (listed below the red line in the table). The students must also plot their projected course grades for the remainder of the semester, under two scenarios: [1] assuming a perfect score on all remaining assignments, and [2] assuming a zero grade on all remaining assignments. The first step is to create a table with the data:

Assignment	Date due	Point value of the assignment	Points earned	Current grade	Point value, zero grade on remaining work	Point value, perfect grade on remaining work	Projected grade based on zero grades	Projected grade based on perfect grades
Lab #1	8/24	10	6	60				
HW #1	8/29	10	7	65				
Lab #2	8/29	10	8	70				
HW #2	8/31	10	9	75				
Lab #3	8/31	10	10	80				
HW #3	9/7	10	9	82				
Lab #4	9/7	10	10	84				
Lab #5	9/12	10	10	86				
HW #4	9/14	10	3	80				
Lab #6	9/14	10	10	82				
Lab #7	9/19	10	9	83				
Lab #8	9/21	10	8	83				
Lab #9	9/26	10	8	82				
HW #5	9/28	10	9	83				
Lab #10	9/28	10	8	83				
HW #6	10/03	10	0	78				
Lab #11	10/03	10	6	76				
Lab #12	10/05	10	7	76				
Midterm exam	10/12	100	80	78				
HW #7	10/17	10	0	75				
HW #8	10/19	10	9	75				
Lab #13	10/26	10	8	75				
Lab #14	10/31	10	6	75				
Lab #15	11/02	10	10	76				
Lab #15 presentation	11/07	10	9	76				
Lab #16	11/14	10	10	77				
Lab #17	11/16	10	10	78				
Lab #18	11/21	10	10	78				
Lab #19	11/23	10			0	10	76	79
Lab #20	11/28	10			0	10	74	79
Lab #21	11/30	10			0	10	72	80
Project presentation	12/05	50			0	50	64	82
Written report	12/05	100			0	100	53	85

The student in this example earned 6 points out of 10 on the first assignment, starting the semester with a 60% average. On the second assignment, the student earned 7 out of 10, for a course average of 65%. The table above and the graph below show that the student's course grade rose above B-, then hovered between B- and C+ for most of the rest of the semester. The black line shows the course grade over time up to the current date; the blue line shows the predicted course grade if the student earns 100% on the remaining five assignments, and the red line shows the predicted course grade if the student earns 0% on the remaining assignments.

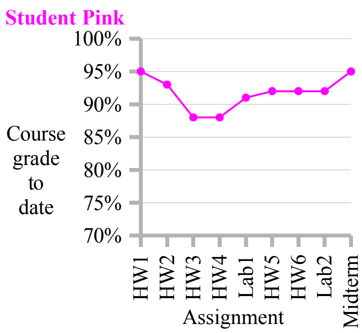


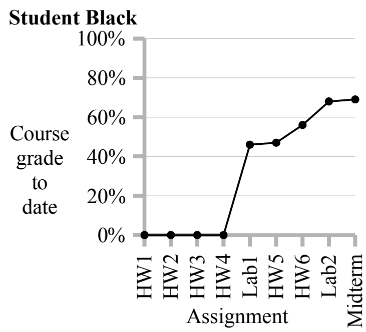
Earning perfect scores on the remaining work will move the student from C+ to a solid B. Earning zero scores on remaining work causes the student's grade to plummet: the C+ quickly drops to F. I ask students to create graph so they will learn how much their course grades can change over time, and so they can see the effect of zeroes in an average.

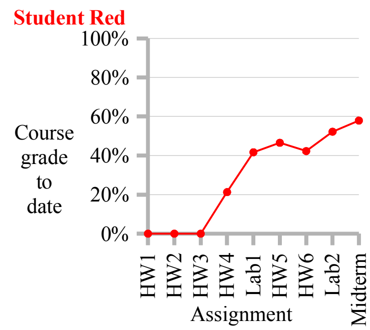
Both the graph and the table contain the same information, but the graph is more compact, and it shows trends visually (it is hard to see a “slope” within tabular data). My Engineering Technology students self-identify as visual learners, so the graph is more appropriate for their learning style.

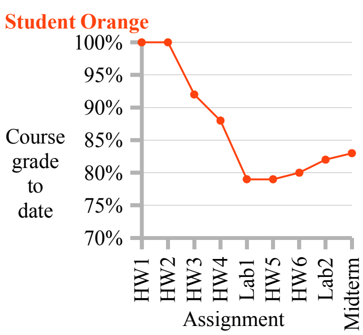
In my experience, B-/C+ students do not suddenly earn 100% on all remaining assignments; nor do they typically stop turning in work for the last two weeks of a course. Instead, they tend to continue at the same level of performance.

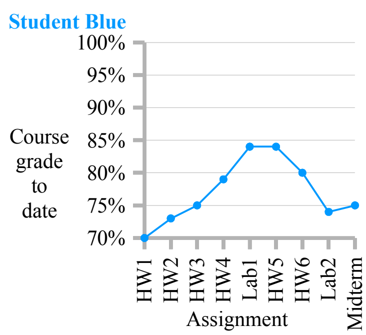
In my freshman *Materials & Processes* class, I create course grade graphs for every student at the midpoint of the semester, and staple each graph to each student's graded Midterm Exam. The passing grade in this class is 70%. In the following course grade graphs from Fall 2014, the vertical scale is 70% to 100%, unless the student has course grades below 70% (Students Black and Red). Students can readily see whether they are improving over time, and whether they are on track to pass the course. Student Black did not have the textbook at the beginning of the course, and was unable to complete the first few reading assignments and homework assignments on time; this student's grades improved once the textbook arrived in the mail.

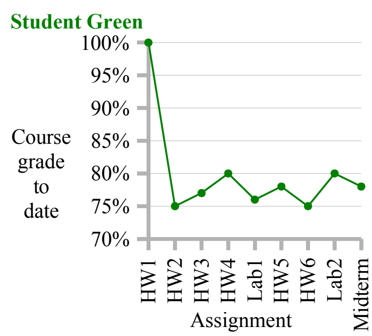












For high-performing students, the graph serves as reassurance; for low-performing students, it serves as a wake-up call. I see much more note-taking during lectures in the second half of the semester compared with the first half.

The graph on the next page shows the grades for all students in the class over the entire semester. Four students started the semester with a zero because they did not submit the first homework assignment. Five of the six students shown above passed the course; here is how they did:

Student Pink consistently performed well all semester, with a perfect score on the Final Exam.

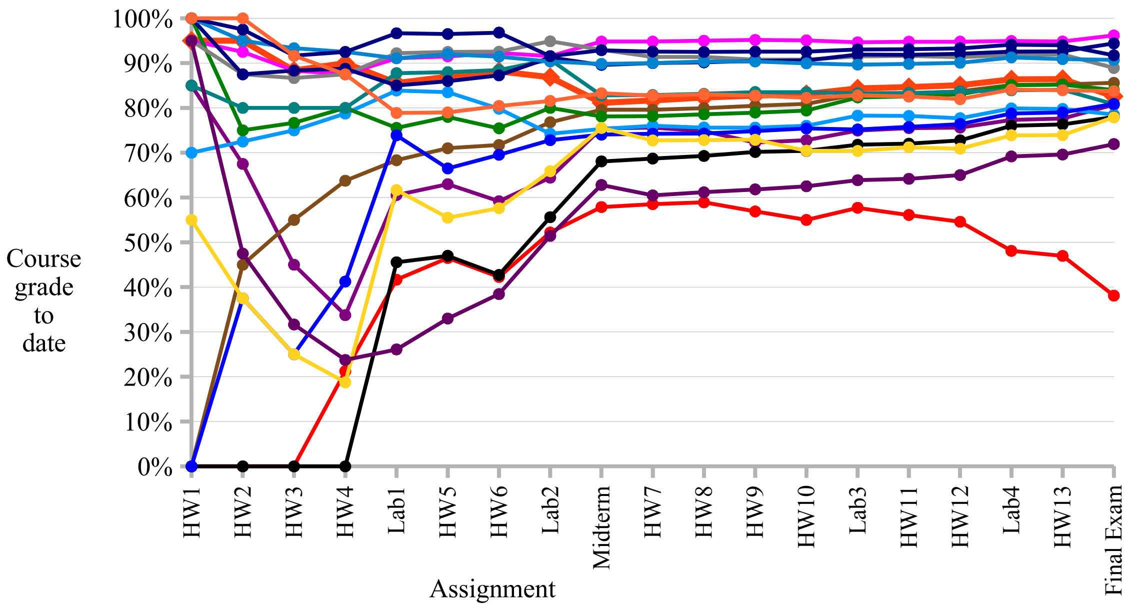
Student Black began submitting work with Lab Report #1, and continued to improve, earning a C for the course.

Student Red submitted 4 of 13 homework assignments, 3 of 4 laboratory reports, and took 1 of 2 exams. The quality of Student Red's submitted work was significantly below average. Not surprisingly, Student Red failed the course.

By the fifth assignment, Student Orange maintained a B-/B grade throughout the semester.

Student Blue's course grade fluctuated between 75% and 85% throughout the semester, ending at 79%.

Student Green's grade settled into the high 70s, but gradually increased in the second half of the semester to 84%.



The trends are typical of all of my courses: as the semester progresses, course grades fluctuate less because more grade entries are in the dataset...a higher *n*. The graph also shows that most students see little change between their midsemester grade and their final course grade. In this section of this course, 60% of the students saw less than a 5 point change in their course grades in the second half of the semester, and 94% saw less than a 10 point change (the exception was Student Red). The trend over many semesters and several different classes is similar:

Course	Level	Sample size	Students with < 5 point change in the second half of the course	Students with < 10 point change in the second half of the course
Intro. Engr. Tech.	Freshman	3 semesters, 54 students	52%	63%
Materials & Processes	Freshman	20 semesters, 366 students	63%	87%
Strength of Materials	Sophomore	10 semesters, 260 students	57%	74%
Intro. Fluid Power	Sophomore	12 semesters, 323 students	78%	93%
Fluid Mechanics	Junior	1 semester, 32 students	56%	91%
Heat Transfer	Senior	2 semesters, 60 students	57%	83%
Instrumentation & Controls	Senior	6 semesters, 105 students	91%	98%

As an instructor, my dilemma is whether to tell students about this observation. If students believe their final course grade is locked in by the middle of the semester, they may be energized to work harder in the first half of the semester to earn a high midsemester average, or they may be tempted to slack off in the second half.

Student Success with Inclined Plane Problems

Professors know that students like to take shortcuts. We show students a methodical but time-consuming solution method to a simple problem, so that students can master the method. Next, we introduce a more difficult problem, where mastery of the problem-solving method is required for a successful solution. In practice, students solve the simple problems using intuitive shortcuts, then these same students trip up on the difficult problems because they have not mastered the methodical solution method.

In my *Introduction to Fluid Power* class, we calculate the hydraulic cylinder size and pump capacity required to move a block at an angle freely through the air at a constant velocity, or up an inclined plane at a constant velocity. The textbook and lecture start with drawing a free-body diagram (FBD), yet many students like to skip this step and start with algebra and trigonometry. Knowing that many students will take this shortcut, I record four data points when grading the homework assignments:

The number of students who draw the FBD correctly and end up with the right answer.

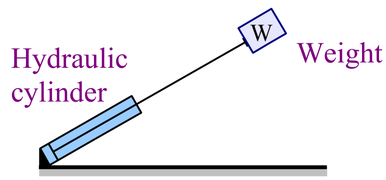
The number of students who draw the FBD correctly but get the wrong answer.

The number of students who draw the FBD incorrectly or not at all, but get the right answer.

The number of students who draw the FBD incorrectly or not at all, and get the wrong answer.

If the block is elevated freely through the air, then many students are able to solve the problem without drawing a free-body diagram. Results for a typical problem[1] over many semesters of teaching this course, are:

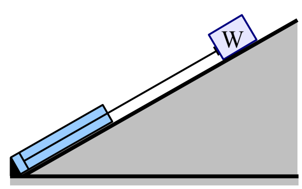
	Right answer	Wrong answer
Correct FBD	33	2
Incorrect or no FBD	38	12



While 94% of students who correctly drew the FBD got the right answer, only 76% of students who failed to draw the FBD correctly got the right answer.

If the block is sliding on an inclined plane with friction, it is very difficult to solve the problem correctly without a free-body diagram. Results for a typical problem[2] are:

	Right answer	Wrong answer
Correct FBD	43	6
Incorrect or no FBD	35	59

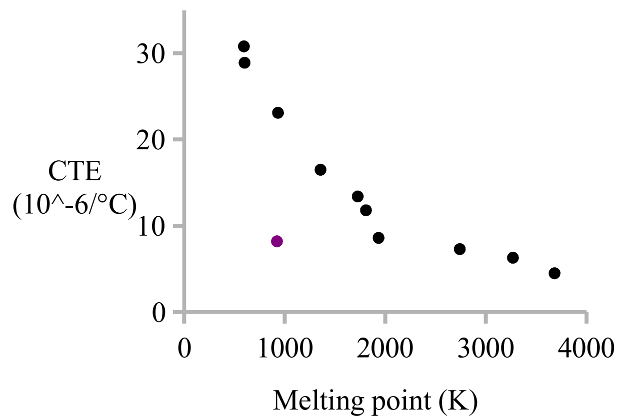


Now the difference between the two groups of students is more dramatic. While 88% of students who correctly drew the FBD got the right answer, only 37% of students who failed to draw the FBD correctly got the right answer. Introducing friction makes the problem too difficult to solve with shortcuts.

When I return the graded homework to the students, I write each table on the chalkboard, with numbers from the class, as well as numbers from all previous classes combined. The students may not believe the textbook author or lecturer who says FBDs are important, but they believe the evidence from their classmates that FBDs make a difference in grades. As a result, most students draw the FBD correctly on the next exam, so the little table is an effective teaching tool.

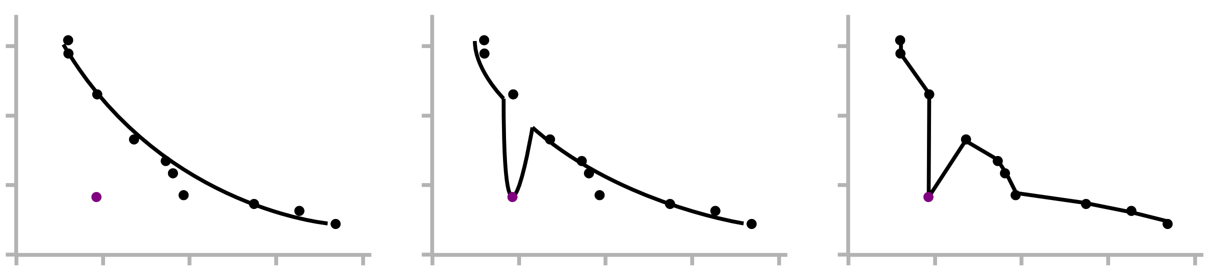
Student Graphing Skills

The textbook for my freshman *Materials and Processes* class contains many tables of materials properties, but lacks a list of linear thermal expansion coefficients for metals. A typical homework problem is to use the internet find the thermal expansion coefficients for a dozen metallic elements, plot these values as a function of absolute melting point, and discuss the graph. When I first assigned this problem in 2004, I did not expect this result:

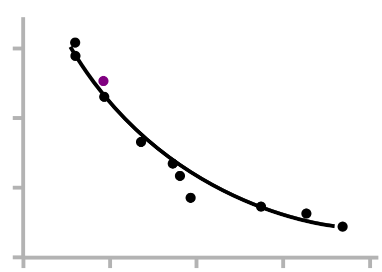


Magnesium (purple point) should have a thermal expansion coefficient close to aluminum (black point almost directly above), but nearly all students placed it at 8×10^{-6} $°C^{-1}$.

Some students assumed the magnesium point was an outlier, and drew a curve through the other points. Other students connected the dots like constellations in the sky. A few students omitted the point from the graph, even though they included the point in their tables.



The reason that the magnesium datapoint appears in a funny place is that someone entered the wrong number on a website. Other website authors simply copied the error to their own websites, rather than looking up the data in a reliable reference book. Interestingly, back in 2004 when I first started asking this homework problem, one of the few websites with the correct value was Wikipedia.

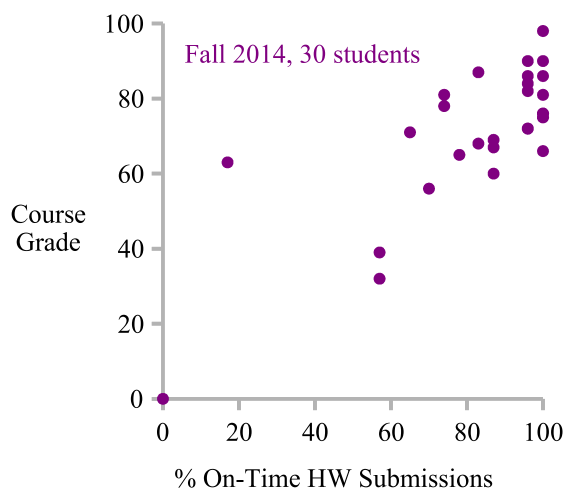


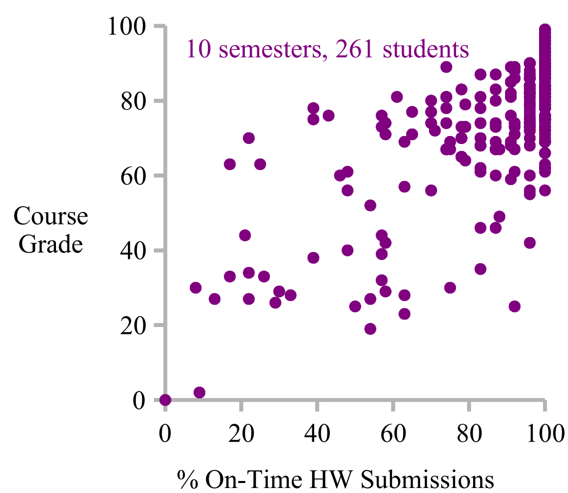
Originally, I intended to use this assignment to teach about bond strength...materials with stronger bonds melt at higher temperatures, and do not expand as much, as materials with weaker bonds. However, the results led to additional discussions in class about the accuracy of data on the internet, and methods for handling outliers.

Does Homework Matter?

Sometimes a scatter plot is not as useful as a table or histogram. In my *Strength of Materials* class, the homework assignments are worth just a few points, so students are penalized very little for not understanding the material on the first try. Twenty homework assignments are worth one exam. I write a completely new set of homework problems each semester, so students cannot copy answers from previous semesters; nor can they find answers online.

The real value of the homework assignments is exam preparation. Some students turn in all homework assignments, while others do not. The graph at the left shows the relationship between homework submission rate and course grade for Fall 2014. A linear regression analysis produces a coefficient of determination $r^2=0.35$, a very weak correlation. The graph at the right includes the most recent ten semesters of this course; now the scatter is greater, and it is difficult to draw meaningful conclusions from the graph.





A more useful way to look at the data is to compare the percentage of students passing the class as a function of the percentage of homework assignments submitted. When homework submission rates are lumped into groups, a pattern emerges.

Homework submission rate	Percentage of students passing the course with a C- or better Fall 2014 (30 students)	Past 5 semesters (160 students)	Past 10 semesters (261 students)
100%	90%	86%	89%
90-99%	100%	83%	83%
80-89%	20%	50%	43%
70-79%	50%	71%	63%
<70%	20%	36%	26%

Based on this evidence, the best strategy for a student is to complete 90% or more of the homework. In class, I show the students the data for the previous 10 semesters to encourage them to complete every homework assignment. The most puzzling aspect of this table: why do students who submit 70-79% of the homework stand a better chance of passing the course than students who submit 80-89% of the homework?

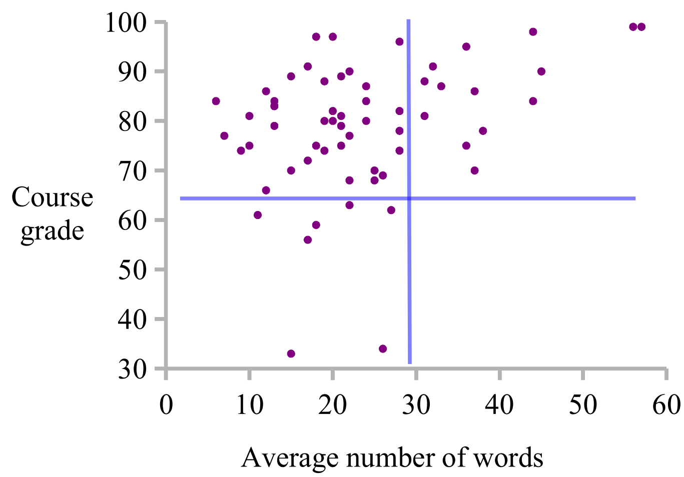
Response Length and Student Success

At my institution, *Strength of Materials* is the hardest class in the Mechanical Engineering Technology and Construction Engineering Technology curricula, based on the percentage of students earning a passing grade of C- or better. The failure rate has ranged between 10 and 30% in the past six years, and is typically 20 to 25%, regardless of instructor. As the primary instructor for this course, my task is to determine indicators of success and root causes of failure in order to make course and curriculum changes to improve the success rate.

One indicator of success in this class is homework completion rate, as described in the previous section. A second indicator of success is the response length to the last problem in each homework set:

> Describe at least one improvement to this chapter to make it more understandable.

I enter all responses into a spreadsheet, and use the information to make changes to the textbook before the next semester begins. (I wrote the textbook for this course during a sabbatical semester. The book is available for free online as a 2 MB pdf file, which is updated every semester, based on student input.[3]) The graph shows the results from three semesters of students. Each point represents a student's course grade and the average number of words used by that student in the 15 chapter responses.



The lower left quadrant shows that students with low grades tend to write very short answers, such as:

> Need more examples.
>
> I would add a Problem #7.
>
> I would appreciate more examples of unit conversions.

The upper right quadrant shows that students who write long responses pass the course with high grades. An example of a long answer (105 words)is full of detail, and includes two suggestions for improvement:

> At the beginning of the lecture it would have been helpful to lay out the different situations we may encounter before teaching any of the types of solutions: 1. steel machine part; 2. steel structural

> columns; 3. ideal long column. This way we would better understand when we are going to end up when solving. Maybe it would also help me to better understand when to use each method. The other misunderstanding I have is on p.110, the formula is σ_{CR} = critical, whereas on p.111 the same formula is σ_{All} = allowable. Shouldn't the one without *F.S.* be critical and with *F.S.* be allowable?

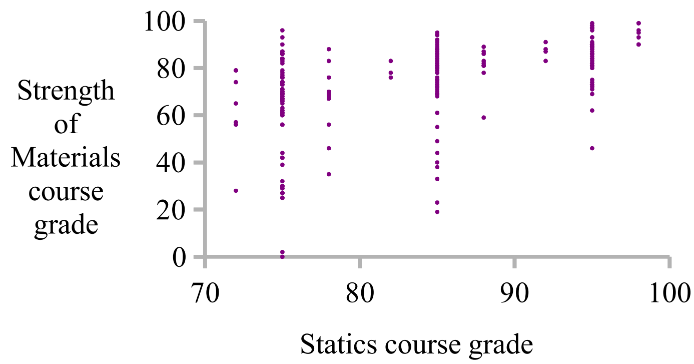
Most students are in the upper left quadrant: they earned passing grades without writing much. Students can pass the class without writing long responses, but students who write long responses all pass the class.

Should I show this graph to students at the beginning of the semester? It may lead some students to write longer responses, thinking it will improve their chances of passing the course. However, correlation is not causation. I like to explain this point to students by describing a young man who observes that among male engineers at his company, bald men earn more on average than men with full heads of hair. He would be foolish to shave his head in hopes of a raise; the oldest engineers are paid the most, and are more likely to be bald.

Students who write lengthy responses may tend to be smarter, harder working, more thoughtful, more literate; or perhaps they are simply better at planning their time. These characteristics lead to higher grades.

Do Prerequisites Matter?

A third indicator of success in *Strength of Materials* is the grade earned in the prerequisite class, *Statics*. This graph shows the relationship between these grades for 222 students taking *Strength* for the first time, across 10 semesters. Students repeating *Strength* are not included in this dataset. In this graph, *Strength* grades are actual numerical grades; *Statics* grades are calculated from letter grades.



The graph is not particularly informative...it does not show any clear trends. In this case, grouping the data in a table is more helpful:

Grade in *Statics*	Percentage of students passing *Strength* with a C- or better
A	95%
B	81%
C	43%

We see that students who do well in *Statics* are more likely to pass *Strength of Materials*. We can learn more by looking at the grade distribution in *Strength* rather than the pass/fail rate:

Grade in *Statics*	Percentage of students in *Strength of Materials* earning each grade				
	A	B	C	D	F
A	41%	43%	11%	4%	2%
B	9%	46%	27%	7%	11%
C	4%	14%	25%	27%	30%

Among students taking *Strength of Materials* for the first time, we see that:

Most students who earned an A in *Statics* earn an A or B in *Strength of Materials*.

Most of students who earned a B in *Statics* earn a B or C in *Strength of Materials*.

Less than half of students who earned a C in *Statics* pass *Strength of Materials*.

This information can be used for advising purposes. A student earning a low C in *Statics* might be better off retaking the course before attempting *Strength of Materials*.

Student Success as a Function of Academic Major

A fourth indicator of success in *Strength of Materials* is the student's major. This table draws from the same dataset as the previous section: 222 students taking *Strength* for the first time. It shows the percentage of students in each major earning an A, B, or C in *Statics*. MET students are more likely to earn an A, and less likely to earn a C, than Construction students.

Major	Grade distribution of students passing *Statics*		
	A	B	C
Mechanical Engineering Tech.	28%	38%	34%
Construction Engineering Tech.	22%	35%	43%

The pattern continues in the grade distribution for Strength of Materials. MET students are more likely to pass *Strength* on the first attempt, and with a higher grade, than Construction students.

Major	Percentage of students earning each grade in *Strength of Materials*				
	A	B	C	D	F
Mechanical Engineering Tech.	19%	38%	18%	11%	14%
Construction Engineering Tech.	7%	26%	30%	19%	19%

Over 10 semesters, on average MET students earn 7 points more on the first exam than Construction students, 6 points more on the second exam, 7 points more on the third exam, and 8 points more on the final exam. There are no obvious significant differences in demographics between the two groups of students. Maybe MET students are smarter...or maybe there is a curricular explanation.

The major difference in the curricula between MET and Construction is unit conversion. MET students take a first semester *Introduction to Engineering Technology* class which emphasizes the Factor-Label Method of Unit Conversion, and the students use this technique in every subsequent MET course. My MET students are familiar with both SI and U.S. Customary units because the local industries that hire MET students use either SI or both unit systems. On the other hand, Construction students do not take *Introduction to Engineering Technology*, and the construction industry in the U.S. almost exclusively uses U.S. Customary units. As a consequence, Construction students are not prepared to perform unit conversions when they start *Strength of Materials*. By the end of the course, they have learned the Factor-Label Method, but low scores early in the semester can prevent these students from passing the class.

The department has taken corrective action by adding *Introduction to Engineering Technology* to the Construction curriculum. The first cohort of Construction students starting the new curriculum took *Introduction to Engineering Technology* in Fall 2014. We should see results starting in the Fall 2015 *Strength of Materials* classes.

Conclusions

We can improve students' awareness of how their grades change over time by asking them to calculate and graph their course grades, and predict their final grades based on assumptions about the grades they will earn on remaining assignments. By including course grade graphs with a midterm exam, a professor can provide useful feedback to students before it is too late to improve a low course grade.

Course grade graphs show that nearly all students finish my courses within 10 points of their midsemester grade, and most finish within 5 points.

Students believe in taking shortcuts when possible. A simple table showing the effectiveness of student strategies (either using a free-body diagram, or not using one) demonstrates the need to use the standard solution method instead of the shortcut. After students have seen the evidence, they are more likely to use the standard method on the exam, and solve the problem correctly.

Course success correlates with homework submission rate, and the best way to show this correlation is with a table rather than a scatter plot. In my *Strength of Materials* course, predictors of success include:

> **Homework submission rate**: Students who submit more than 90% of homework assignments earn higher grades than students who submit less work, and pass the course in larger numbers.
>
> **Prerequisite**: High grades in *Statics* are associated with high grades in *Strength of Materials*.
>
> **Wordiness**: Longer written responses on homework assignments correspond with high final course grades, and low course grades correspond with short responses.
>
> **Major**: Mechanical Engineering Technology students perform better than Construction Engineering Technology students.

This last observation led to a curriculum change which will improve Construction Engineering Technology students' knowledge and skill at performing unit conversions.

[1] Anthony Esposito, *Fluid Power with Applications*, 7th ed. Prentice Hall, 2009. Problem 6-23, p. 227.
[2] Ibid, Problem 6-25, p.227.
[3] (Reference to previous ASEE papers on this textbook to be added after blind peer review is completed).