How to Write a Textbook in Ten Easy Steps

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Abstract

Strength of Materials is the most difficult course in the first two years of the Mechanical, Civil, and Architectural Engineering Technology programs at Indiana University – Purdue University Fort Wayne (IPFW); consequently it has the highest drop and fail rate. In the past decade, the failure rate in our *Strength* courses has ranged from 10 to 30% each semester, under three different professors, using the same algebra-based textbook. Students have trouble using algebra...they prefer to plug numbers into canned equations. The Civil and Architectural students struggle with unit conversions. Although professors provide office hours during the day, most students work on homework in the evening and on weekends, and report that the explanations in the text are insufficient, too wordy, or too difficult to understand at midnight. A root cause of these problems is the editing process; most textbooks are edited for technical content by other professors, so they are technically excellent. However, they are not edited for understandability by the target audience, so many undergraduates find them difficult to understand.

To solve these and other problems, I spent a sabbatical writing a new *Strength* textbook for Engineering Technology students. Each semester, these students submit editorial changes, for extra credit. Feedback must be both specific and actionable: "this chapter is confusing" does not meet either criterion, whereas "I don't understand how to solve the moment in Example 6, page 45" meets both criteria. A student may not know what to change, but can easily identify the confusing parts of a text. The book is free, available as a pdf on the course website, and is updated on an ongoing basis.

This paper discusses the writing process, delivery via pdf instead of print, selection of topics requiring extra emphasis, editing assistance from students, and the improvement in learning outcomes. Although the topic of the book was *Strength of Materials*, this paper discusses techniques that can be applied to a variety of undergraduate engineering textbook topics.

Introduction

I teach *Strength of Materials* to Architectural, Civil, and Mechanical Engineering Technology students. Students in the ARET, CET, and MET programs at IPFW must earn a C- or better in *Strength* in order to pass the course. Table 1 shows the percentage of students needing to repeat *Strength* due to low grades, along with the repeat rate in all other MET courses.[1] Based on a 20% mean repeat rate, *Strength* is apparently the hardest course in the curriculum. The table does not include students who withdrew from courses because of low grades. When withdrawals are included, the repeat rate in *Strength* runs between 18% and 35%.

Table 1: Percentage of students in each course who must repeat the course, from Fall 2008 to Fall 2011. Mean values are the total number of students needing to repeat in all semesters divided by the total number of students enrolled in all semesters. A blank cell indicates the course was not offered that semester.

Course	F08	S09	F09	S10	F10	S11	F11	Mean
Intro. Engr. Tech.	3%	6%	15%	16%	8%	14%	8%	9%
2-D CAD	11%	7%	11%	11%	6%	13%	6%	9%
Materials I	25%	16%	6%	10%	16%	5%	16%	12%
Statics	4%	5%	20%	14%	12%	9%	12%	12%
Strength of Materials	16%	10%	25%	21%	25%	20%	25%	20%
Fluid Power	3%		0%		7%		7%	4%
3-D CAD		8%	6%	12%	0%	6%	0%	6%
Machining	0%	0%	0%	0%	6%	0%	6%	2%
Machine Elements		0%		3%		0%		1%
Tool Design	5%		5%		0%		0%	3%
Fluid Mechanics		4%		0%		0%		1%
Dynamics & Mechanisms		0%		0%		0%		0%
Materials II		0%		3%		0%		1%
Automatic Systems		0%	0%	0%	0%	0%	0%	0%
Instrumentation & Control	0%				0%		0%	0%
Thermodynamics	0%		14%		11%		11%	10%
Heat Transfer		0%		0%		0%		0%
Senior Design		0%		0%		0%		0%

Three different instructors teaching *Strength of Materials* have had the same general outcome using the same textbook.

1.5 million bachelors degrees are awarded annually in the US.[2] About 70,000 are Engineering degrees, and about 15,000 are Engineering Technology (ET) degrees and Technician degrees. The number of Mechanical, Civil, and Construction Engineering Technology graduates is less than 2,000 per year, so the market for algebra-based *Strength of Materials* textbooks for ET is a small fraction of the market for calculus-based Engineering textbooks. The few ET *Strength* books are technically excellent, but are not always easy for undergraduates to understand.

My students complain that the explanations in many Engineering Technology textbooks are too theoretical, too wordy, and too difficult to understand. They also complain about the lack of complete unit conversions in example problems, and inconsistent use of symbols between related courses. For example, some authors use s_n, s_s, and e for normal stress, shear stress, and strain, instead of the standard Greek symbols σ, τ, and ε. This use of Latin characters with multiple subscripts confuses students because the Greek symbols are used in textbooks for other courses, and because capital S is used for section modulus later in this course. Students have trouble distinguishing between s and S on the chalkboard during lectures (and in their notes).

My students also complain about the high cost of textbooks. In the last 30 years, textbook costs have risen about twice as fast as inflation, so this is a reasonable complaint.

To address these issues, I decided to use my first sabbatical to write a tailor-made textbook for my students. When I went to college in the 1980s, printed textbooks were the only option. These books were updated once every 4 to 10 years based on input from experts in the field, typically other college professors. Today, the internet offers another option: low-cost or free e-books available online which can be revised more frequently than printed books. As an added benefit, color is free on electronic displays (laptops, cell phones, pad devices). For all of these reasons, I decided to provide the textbook to the students as a pdf file, available for free on the university's website.[3]

The Writing Process

Early in the writing process I looked for software that is inexpensive, easy to learn and use, does not crash frequently with large files, handles graphics and equations easily, and produces a reasonably small pdf file (less than 4 MB) for the finished textbook.

Table 2: Software comparison

Software	Advantages	Disadvantages	Equations	Graphics
MS Word (Microsoft Corp.)	Easy to learn	Crashes with large files; produces very large pdf output file; MathType equation formatting too automatic	MathType	Images are bitmaps (insufficient resolution in pdf file)
Pages Apple Inc.)	Easy to learn	Limited user control in formatting graphs; MathType equation formatting too automatic	MathType	Primitive
Scrivener (Literature & Latte)	Great for all-text documents such as novels; master document links individual chapter files	No page layout features for images, tables, equations (output must be formatted by additional software such as MS Word)	MathType	None
Apache Open Office (Apache Software Foundation)	Free; does not crash with large files; master document links individual chapter files; file opens at last saved place, not top of the document; pdf output very small.	Equations unreadable if there are too many in the document (must split document into multiple files) Need to learn equation software	Open Office Math (similar to LaTex)	Includes easy-to-learn graphics software with high resolution output

Software cost was not really an issue because of academic discounts. Crash-resistance, the ability to produce high-resolution diagrams, formatting control of equations, and final pdf file size were the main criteria.

Apache Open Office met the needs best, and had the least significant disadvantages. Graphics are outstanding, equations are easier to create with vertical lines separating unit conversions, and the software is less prone to crashing than MS Word.

The next step in planning the book was to select a common set of symbols. All *Strength* textbooks use *E* for Young's modulus, but there is less agreement between textbook authors for quantities such as normal stress, shear stress, radius of gyration, and other terms listed in Table 3. I tended to select the most recently used symbols because students are more likely to see them in other courses such as *Statics*, *Materials I* and *Machine Elements*.

Table 3: Symbols used in various *Strength of Materials* textbooks. The Engineering Technology (ET) texts are mostly algebra-based, while the Engineering (E) texts use algebra and calculus.

Textbook:	A[4]	B[5]	C[6]	D[7]	E[8]	F[9]	G[10]	H[11]	I[12]	J[13]	K[14]	L[15]	M[16]
1st edition	'08	'07	'01	'91	'88	'85	'81	'76	'69	'53	'49	'47	'30
Edition used	'08	'07	'04	'09	'88	'97	'06	'76	'69	'53	'49	'62	'56
ET or Engineering	E	E	E	ET	ET	ET	E	E	ET	E	E	ET	E
Normal stress	σ	σ	σ	s	σ	σ	σ	σ	σ	S	s	s	σ
Shear stress	τ	τ	τ	s_s	τ	τ	τ	τ	τ	S_s	s_s	s_s	τ
Strain	ε	ε	ε	e	ε	ε	ε	ε	ε	ε	ε	ε	ε
Poisson's ratio	ν	ν	ν	μ	μ	μ	ν	μ	μ	μ	μ		μ
Point load	P	P	P	P	F	P	P	F	P	P	P	P	P
Stress concentration	K	K	K	k	k	K	K	K_t					k
Radius of gyration		k	r	r	q		r	k	k		k		k
Section modulus				S	Z	S		Z	Z		Z		
Plastic section modulus				Z		Z							

The textbooks referenced in Table 3 were a great resource for selecting topics and deciding on their order. Most textbooks in this field intentionally contain more information than can be effectively covered in one semester, so the instructor can tailor the course to the needs of the students by including or dropping particular sections. Since I was writing a book for a specific audience at one institution, I eliminated extra topics that my students do not need (such as the Moment-Area theorem), and added a topic that my Architectural and Civil Engineering Technology students are deficient in: unit conversions.

The table of contents on the next page shows how the book starts with a chapter on the Factor-Label Method of Unit Conversion, then moves through the easier *Strength* topics such as thermal expansion, pressure vessels, and bolted joints. Students develop problem-solving techniques and practice unit conversions with easy problems. These skills help students with subsequent harder topics such as beam analysis and Mohr's circle.

Table 4: Table of contents of the textbook.

The best *Strength* textbooks include a list of terminology (with typical units), either at the beginning of the book or in an appendix. I added a set of definitions, because my students tend to forget the meanings of the terms.

Algebraic Problems

In conversation and by their work, my students tell me they want help with algebra skills, unit conversions, and problem-solving approaches. The new book contains problems requiring an algebraic answer as well as traditional problems requiring a numerical answer. For example, here are problems for the chapter on stress and strain for the Spring 2013 semester:

1. Calculate the strain in a 2½ in. long rubber band that is stretched to a total length of 4¼ in. [%]
2. Calculate the strain in a 12 m long bar if it stretches 5 mm. [unitless, decimal number]
3. A round rod is loaded under a tensile load *P*. Using $\sigma = \dfrac{P}{A}$, develop an algebraic equation for calculating the diameter, *d*, such that *d* is a function of *P* and σ.
4. Use the previous equation to find the diameter of a rod that will support a tensile load of 4 kips if the allowable stress is 36,000 psi. [in.]
5. Using $\delta = \dfrac{PL}{AE}$, develop an algebraic equation for calculating the diameter, *d*, of a round rod such that *d* is a function of *P*, *L*, δ, and *E*.
6. Use the previous equation to find the diameter of a 6 m long rod that will support a tensile load of 130 kN and stretch no more than 2.5 cm, if Young's modulus is 110 GPa. [mm]
7. A 25 ton stamping press is used for punching circles out of sheet metal with a shear strength of 22 ksi and a thickness of 0.032 in. What is the largest diameter circle that the press can produce with a flat punch? [in.]

Problems 1, 2, 4, 6, and 7 are "plug & chug" problems that students prefer; however, in order to solve problems 4 and 6, students must first derive algebraic expressions in problems 3 and 5.

The Factor-Label Method of Unit Conversion is emphasized from the first chapter, and is used in all example problems.

Refer to Older Books...but Check Sources

I found that other textbooks are a good guide for content, difficulty level, ways to explain topics, and layout. For example, the best texts display illustrations on the same page as the relevant text, they include an easy-to-find list of terminology, they list the key equations at the end of each chapter, and they have good indices. Unfortunately, some authors borrow content from older textbooks without verifying accuracy. For example, some *Strength* textbooks discuss wrought iron and its use in water pipes as if it were a current material; in fact, wrought iron has not been used for water pipes since the early 20th century. The last wrought iron factory in the world closed in 1973.

Selection of Topics Requiring Extra Focus

Some topics are harder for students to learn, and therefore need more explanation and more examples. I looked at the average grades over 7 semesters on the various homework assignments and ranked them in Table 5. The most troublesome three topics differ from the rest in that they require multistep problem-solving techniques; the easiest topics require simple one-step calculations.

Table 5: Average grade from Fall 2008 to Fall 2011 for each homework topic, sorted from low to high grade. The lowest three grades were on topics requiring a multistep problem-solving technique.

Topic	Average grade over 7 semesters
Shear & moment diagrams	50
Moment of inertia of a compound shape	57
Beam design	59
Stress & strain	60
Elongation / thermal expansion	62
Bending stress in beams	62
Combined stresses / short blocks #1	65
Bending & shear stresses in beams	65
Combined stress cases	66
Bolted connections	67
Columns	67
Shear stress in beams	68
Beam reactions / shear diagrams	69
Statically indeterminate beams	70
Formula Method	71
Columns	71
Welded connections	73
Torque	74
Combined stresses / short blocks #2	78
Torsional stresses	78
Pressure vessels	78
Stress concentrations	79
Beam deflection with the Formula Method	81

Finding the moment of inertia of a compound shape requires the student to build a diagram and calculate many dimensions and intermediate quantities. In the classroom, the professor builds the diagram on the board in real time, like a movie; however, the finished product in a student's notebook only shows the final frame of the movie. A better way to teach this topic is to show the students each movie frame. I created a study guide[17] for calculating moment of inertia "in 10 easy steps", posting it on the web. In the study guide, the student can follow a frame-by-frame solution for each example problem. I also created study guides for drawing shear and moment diagrams, and for beam analysis; these three guides became the core of the new textbook.

The method for drawing a shear diagram is shown below in 6 diagrams. Accompanying text and equations are aligned with each diagram. Each image builds on the previous frame, until the shear diagram is complete.

We can sketch V as a function of location along the beam using
below the load diagram wherever the applied loads and reaction
indicating zero shear load. Next, draw the value of V along the l

30 kN

15 kN   4 m   4 m   15 kN

Step 1 Starting at the left side of the shear diagram, go up 15 kl

Step 1

Step 2 There are no additional loads on the beam until you get t

Step 2

Step 3 The applied load at the midspan is 30 kN downwards, th
$$15\,\text{kN} - 30\,\text{kN} = -15\,\text{kN}$$

Step 3

Step 4 There are no additional loads on the beam until you get t

Step 4

Step 5 At point B, the reaction force $R_B = 15$ kN upwards, there
don't get to 0, you know you 15 kN a 15 kN ce 0omeplace.

Step 5

Finish the shear diagram by shading the areas between your
significant points (anywhere the shear line changes direction
absolute value of shear load, $|V|_{max}$, to calculate the maximum shear stress in the beam.

Finished shear diagram

Since shear and moment diagrams give students more trouble than any other topic, the shear and moment chapter includes 22 fully worked examples.

Notice the use of color in the shear diagram example. Color is used throughout (on 87% of the pages) to differentiate between dimensions lines and construction lines, between applied forces and reaction forces, between solid and hollow sections, between applied loads and beam weights. I avoided mixing green and red colors in the same diagram, and asked if any colorblind students to tell me if any color combinations caused trouble; no student reported any problems. Some students chose to print the book in color because color printing is widely available and cheap; others brought laptops or electronic pad devices to class.

Editing Assistance from Students

I awarded extra credit points to students who submitted recommendations for improving the textbook. Of the 25 students who took the final exam, 6 submitted recommendations...a 24% response rate. This rate is substantially lower than the extra-credit participation in the previous two semesters, when students were asked to recommend changes to study guides posted online. The response rate on the study guides was 50% and 55% in Fall 2011 and Spring 2011, respectively.

Textbook feedback was specific and actionable: every comment referred to a particular issue on a particular page of the book. Most comments regarded typographical errors, but some discussed clarity. For example, the problem set referred to the "tabular method" of solving moment of inertia problems of compound shapes. Although tables were used in the method discussed in the textbook, I never used the term "tabular method" in the textbook, confusing a student who did not understand the term.

One student suggested:

> Include a few more examples in Chapter 11 on beam design where when adding in the weight of the beam the max. moments are not at the same spot for both point load and weight of the beam.

This recommendation was easy to implement by changing an example problem. Another student remarked:

> I found Chapter 15 very confusing. I think the 6 steps for Mohr's circle would be better if you have a list of points defined and not associated with the concept of the three sine waves from page 5. It should be separated from the previous material, and then it would better flow into examples 1, 2, and 3. This would be a lot clearer on how to go thru the steps. I made the homework way harder than it was, trying to follow the chapter.

This student occasionally missed lectures because of his job, so he often relied solely on the textbook to help him solve homework problems...this may have been the case with the Mohr's circle problems. Students who attended the lectures more regularly did very well on this particular assignment. I need to review the chapter and my lecture notes, and make sure the explanation in the textbook is written more clearly.

Assessment and Lessons Learned

Summarizing, the goals of this book are:

- Free or low-cost distribution of a file smaller than 4 MB over the internet
- Frequent revisions based on student input
- Concise explanations
- Examples with complete unit conversions
- Standard Greek symbols for stress and strain
- Problems requiring algebraic answers as well as problems requiring numerical answers
- Problems requiring answers in sentences to show reasoning and understanding of the topics
- Lower failure rate in *Strength of Materials* classes through better learning

The first seven goals were met: the 2 MB pdf file is freely available online; the book is revised every semester; explanations are clearly concise because the book is a fraction of the length of a conventional textbook; all examples have complete unit conversions and use standard symbols; about 10% of the problems are algebra-only.

Given the low participation rate in the extra-credit option for submitting editing suggestions, I have added a required question to every chapter-ending homework assignment:

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

By phrasing the question this way, I am receiving more useful feedback in the Spring 2013 section. As of the end of February 2013, the response rate is 86%.

The final and most important goal, reducing the repeat rate in this class through better learning, was not achieved. I had hoped to reduce the repeat rate to 10% or less. In this first semester of using the new book the repeat rate was 24%...no different than recent semesters. Four students failed the course outright; none of these four showed up for the final exam.

At the end of the semester, students complete a course survey. One question asks the students to rate the textbook on a scale of 1 to 4: poor, fair, good, and excellent. Table 6 shows that the average evaluation score from 15 semesters of classes rose from 3.01 out of 4 to 3.67 out of 4...the highest score I've ever seen on this question in any course. What is not clear is the reason for the increase...is it because students like the electronic format, because the book was tailor-made for them, or because it was free?

Table 6: Student evaluation score on question "The textbook: 4) Excellent, 3) Good, 2) Fair, 1) Poor" in my section of Strength of Materials each semester.

F03	S04	F04	S05	S06	S07	F07	S08	F08	S09	F09	S10	F10	S11	F11	F12
2.80	3.08	3.17	3.33	3.00	2.95	3.07	2.92	2.88	3.10	2.62	3.30	3.00	2.94	3.00	3.67

Further Work

Tailor-made textbooks available for free as pdf files can have a positive impact on student learning and student satisfaction. Out-of-print textbooks are already available online, often on their authors' websites. The next step is to create a clearinghouse for free textbooks...perhaps ASEE could provide this as a service to its members. In the meantime, I plan to develop another pdf textbook for one of my courses following 10 easy steps:

1. Select a software package for writing and diagrams
2. Select symbols, referring to other textbooks as guides for currently used symbols
3. Use other textbooks as references, but verify facts – avoid propagating errors
4. Decide on the order of presentation, and create a list of chapters
5. Review grades from previous semesters to select topics requiring extra focus
6. Write the chapters (the most time-consuming step)
7. Use step-by-step illustrated examples for multistep solution methods
8. Write a new set of homework problems each semester
9. Post the textbook as a pdf
10. Solicit feedback from students for improving the next version of the textbook

[1] Data from grade distribution reports, available at http://new.ipfw.edu/microsites/university-archives/administrative-archives/

[2] Data from 2007-2008. Updated numbers are available online in the Digest of Educational Statistics, published by the National Center for Educational Statistics, U.S. Department of Education.

[3] http://www.etcs.ipfw.edu/~dupenb/ET_200/Applied%20Str%20of%20Mat%20for%20ET%20v3%20Jan%202013.pdf

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