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How to Improve a Textbook with Engineering Technology Students

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How to Improve a Textbook with Engineering Technology Students

Abstract

Strength of Materials is the hardest 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 (between 18% and 30% per semester). A previous ASEE paper described the process for creating a new textbook designed to help students learn better and pass the course in larger numbers. The textbook is free, available online as a 2 MB pdf file. This paper focuses on continuous improvement of the textbook. While commercially-produced textbooks are updated once every four to ten years, the new textbook is updated every semester based on student feedback. In the first semester of the new textbook's use, feedback was optional and worth extra credit points. Unfortunately, only the most desperate students participated, and the quality of the responses was inadequate. Subsequently, feedback was incorporated into the homework assignments as a course requirement, with better than 90% participation. Feedback must be both specific and actionable: "this chapter is confusing" does not meet these criteria, 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.

This paper presents an analysis of the quality and quantity of feedback responses, with examples of positive effects on the textbook over the past three semesters. Although the topic of the book is *Strength of Materials*, this paper discusses techniques that can be applied to a variety of undergraduate engineering textbook topics.

Introduction

I spent a sabbatical semester writing a *Strength of Materials* textbook tailored to the needs of Architectural, Civil, and Mechanical Engineering Technology students at IPFW. The writing process is described in a previous paper,[1] along with the reasons for writing the book: to make the text more understandable and less wordy, to reduce textbook costs, to use standard Greek symbols for shear and normal stress, to create new homework problems every semester (to reduce copying), to introduce algebraic homework problems, and ultimately, to reduce the failure rate. Since the textbook is electronic, I was able to use color extensively, because color is free on a laptop, pad device, or cellphone. The textbook is available to the students as a 2 MB pdf file, free on the university's website.[2] The great benefit to an electronic book is frequency of revision. Commercially-produced textbooks tend to be updated once every 4 to 10 years, so if there is an error or a confusing passage, 8 to 20 semesters of students are educated with the flawed book before corrections are introduced. It is hard to imagine any other manufactured product with known flaws remaining on the market for so long without *some* change in design, processing, or materials. This new textbook has become a good example to students of Continuous Improvement in action.

The textbook topics are organized as follows:

Preface	Introduction to the book
Editors	List of all students who have edited previous editions of the textbook
Terminology	List of symbols and their meaning, along with typical units; Greek alphabet
Definitions	Terms with their symbols and definitions
Chapter 1	Introduction to Strength of Materials; the Factor-Label method of unit conversion
Chapter 2	Normal and shear stress & strain
Chapter 3	Poisson's ratio; thermal expansion
Chapter 4	Pressure vessels; stress concentrations in flat plates with holes, fillets, or grooves
Chapter 5	Bolted joints; welded joints
Chapter 6	Properties of areas: centroids, moment of inertia of simple shapes, the Transfer Formula and moment of inertia of compound shapes, radius of gyration, polar moment of inertia
Chapter 7	Torsion in round shafts: shear stress; angle of twist; stress concentrations in stepped shafts
Chapter 8	Beam reactions, shear diagrams, & moment diagrams
Chapter 9	Bending stress & shear stress in beams; allowable load
Chapter 10	Beam deflection & superposition
Chapter 11	Beam design for steel or timber beams
Chapter 12	Combined stresses: tension + bending; bending in two directions; eccentric loading
Chapter 13	Statically indeterminate beams
Chapter 14	Column buckling: ideal, structural steel, & steel machine parts
Chapter 15	Visualizing stress & strain; Mohr's circle
Appendices	Unit conversions; engineering materials; properties of areas; steel beams; steel pipes; copper pipes; wood; dimensional lumber; beam equations
Index	Key terms (first instance, generally)

Student Feedback

In Fall 2012, the first semester of using the new textbook, I invited students to provide feedback in exchange for extra-credit points. Of the 25 students in the class, only the 6 students most desperate for points 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.

Starting in Spring 2013, I added this required homework question at the end of each chapter:

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

I typed the responses from three sections of this class into a spreadsheet for analysis. These sections comprised one class of 26 students in Spring 2013, and two classes of 12 and 23 students each in Fall 2013. Multiplying 61 students by 15 book chapters results in 915 possible responses. The actual number of *useful* responses was lower because not every homework assignment was submitted, not every student answered the improvement question, and not every answer was useful. The percentages in Figure 1 reflect only the submitted homework assignments.

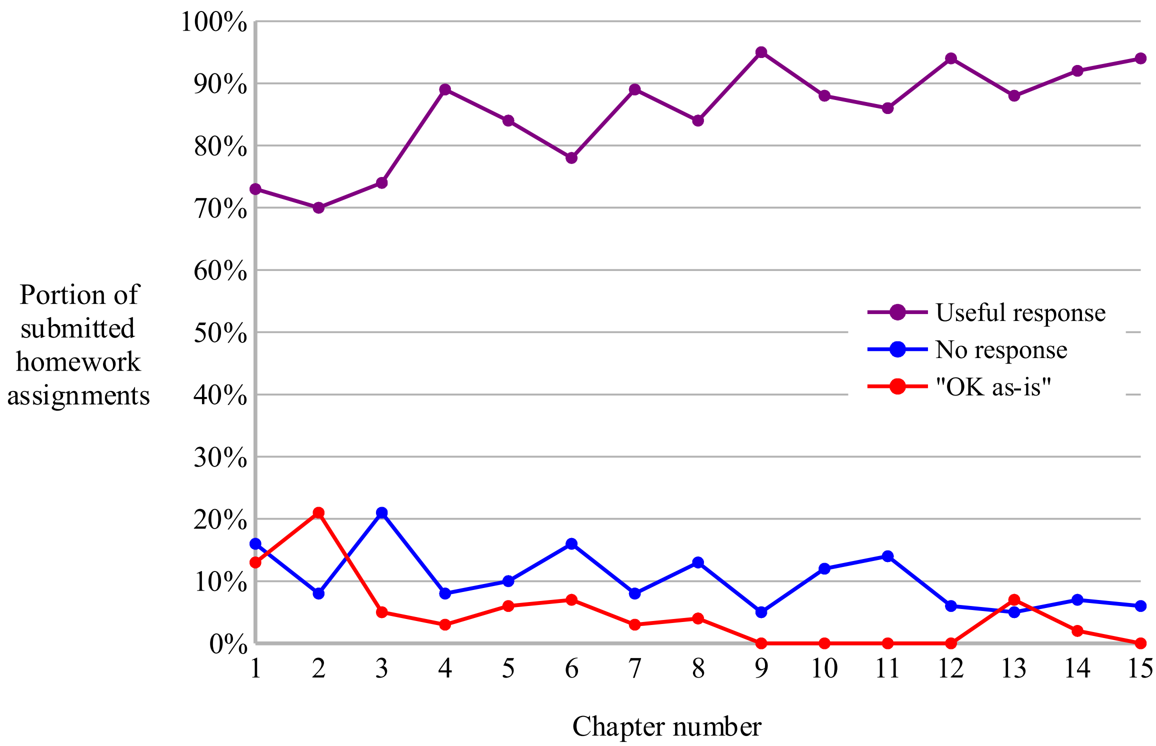

Figure 1: The percentage of students who responded "the chapter is fine as it is" or did not answer the question dropped as students realized the question was graded. Useful responses increased over time.

At the beginning of each semester, some students responded with some variation of "the chapter is fine as it is." This type of response does not answer the homework question, so I marked it wrong. Once students realized the homework question was actually graded, the "OK as-is" responses evaporated. "OK as-is" represents 41 submissions in Figure 1.

Some students did not answer the question, perhaps because they ran out of time, or did not believe the problem would be graded. Again, this percentage dropped as the semester progressed. "No response" represents 82 submissions in Figure 1.

The remaining responses included answers that were useful to some degree. As the semester advanced, the percentage of useful responses rose from around 70% to around 90%. There were 638 useful responses. These responses fell into one or more of 10 categories, with two thirds of all responses falling within the first two categories.

1. Provide more examples of a specific nature – *37% of all responses*
2. Clarify a particular concept – *29%*
3. Improve the formatting (such as adding chapter headings to every page) – *9%*
4. Provide more examples (no particular type) – *7%*

5. Provide more examples in S.I. units, or in U.S. Customary units – *4%*
6. Provide more unit conversion examples using the Factor-Label Method – *4%*
7. Fix typographical or other errors – *4%*
8. Provide references to data in the Appendices within the chapter – *3%*
9. Assign more homework problems (strange...but true!) – *2%*
10. Improve the index – *0.2%*

Figure 2 shows that requests for specific examples rose as the semester progressed. Typically, students asked for examples that closely or exactly matched homework assignments, as in these responses:

> An example similar to problem 14 would have been nice. We did enough to really figure it out, but I'm not 100% sure if I'm right. I'll put it this way…I wouldn't put 5 bucks on it.
>
> Include an example like homework problem #4.
>
> More examples of problems 1-4. Nothing in the book or your notes helped me. I know I am not the only one that doesn't understand this either.

It is not a great surprise that the last student never took advantage of office hours.

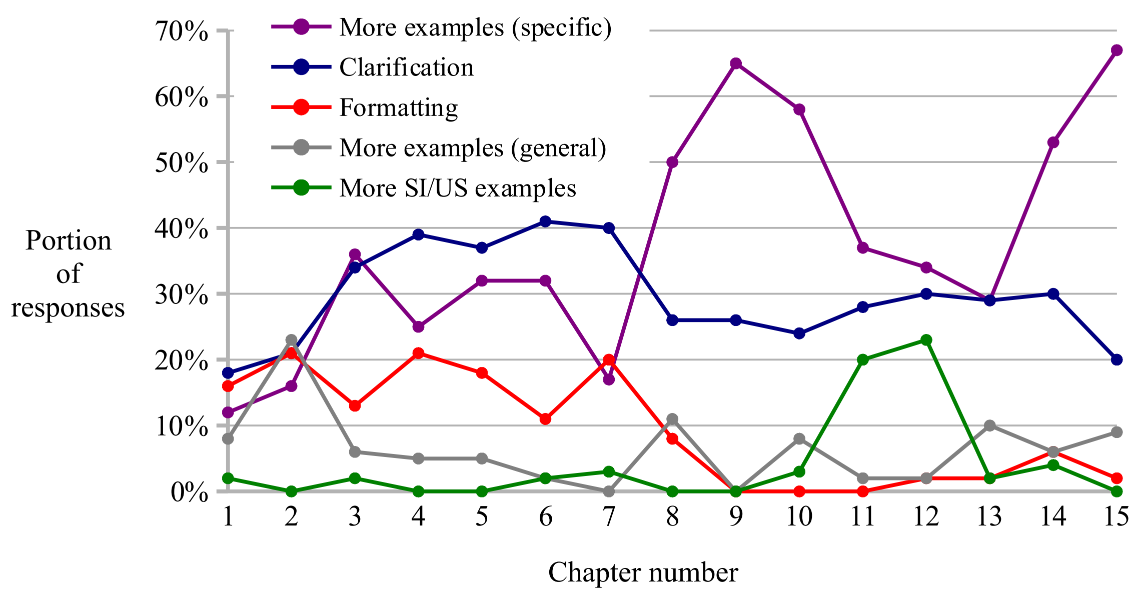

Figure 2: The percentage of responses in each of the first five categories changed as the semester advanced.

Often students requested an example to help them learn a concept. For example, calculating the moment of inertia of a compound shape is demonstrated with respect to the x axis only; many students asked to see an example where it is calculated with respect to the y axis. Other responses include:

> I would appreciate more examples of unit conversions.

> Give an example of a cantilever beam with nonuniform load to show what the moment and shear load diagram.

> Put an example on how to calculate percentages.

The second most common type of request was for more clarification on a particular concept. Examples include:

> I was having trouble with shear stress and shear strength. Are these terms interchangeable?

> I was a little unclear about the units of α [thermal expansion coefficient] from Appendix B. In the thermal stress section I was glad to see the units cleared up.

> Explain the difference between thin- and thick-walled pressure vessels.

> I would go more in depth about if you are welding two different plates together with different thicknesses, such as problem #4. It was just confusing what size weld to select.

> I am not sure what polar moment of inertia really is.

> I struggled with graphing the moments and believe a well-written paragraph about how to do this would be very useful. The signs (+, -) were challenging.

> Explain weld efficiency in more detail. Explain why it's important.

Although students may not know how to reword a passage, they clearly know which parts are confusing or incomplete. The examples above are specific and actionable, as opposed to a generic “Provide more examples” (the fourth category). Figure 2 shows that Chapters 11 and 12 contain examples that are in only one unit system; students want to see examples in both SI and US Customary units.

One of the most interesting conceptual questions centered on moment of inertia (second moment of area):

> What does $unit^4$ mean? I understand and can picture $unit^2$ and $unit^3$. What is the 4^{th}?

Figure 3 includes the five categories with the least number of responses. Requests for unit conversion examples dropped off quickly as the semester progressed, because every chapter contains examples of unit conversions. Notice the peak in Chapter 13: this chapter had too few homework problems, and students noticed. Students found 24 typographical and other errors; examples include:

> There is an error in Example 2. I think the problem states that the answer should be in MPa but the unit conversion uses kPa.

> Page 16, footnote 3, there is a missing space before "Thomas".

On page 32 in the text you work out all problems in kN. When you went to solve your efficiency for joints, the units were kips…why? Shouldn't it be kN?

Typo: page 64, $V_4 = -50$N, not -250N

Appendix E p. 144, in the explanation of how to find the weight of a wooden beam, you listed 200×300. I believe you meant 200×360 as the example.

Step 5 of the first compound beam example has $a \cdot y$ units in in.^{2} instead of in.^{3}.

Of course, these errors are very easy to fix. The last comment was interesting because I had fixed the problem before the semester started; this student was taking the class for the second time, and had not downloaded the most recent version of the textbook.

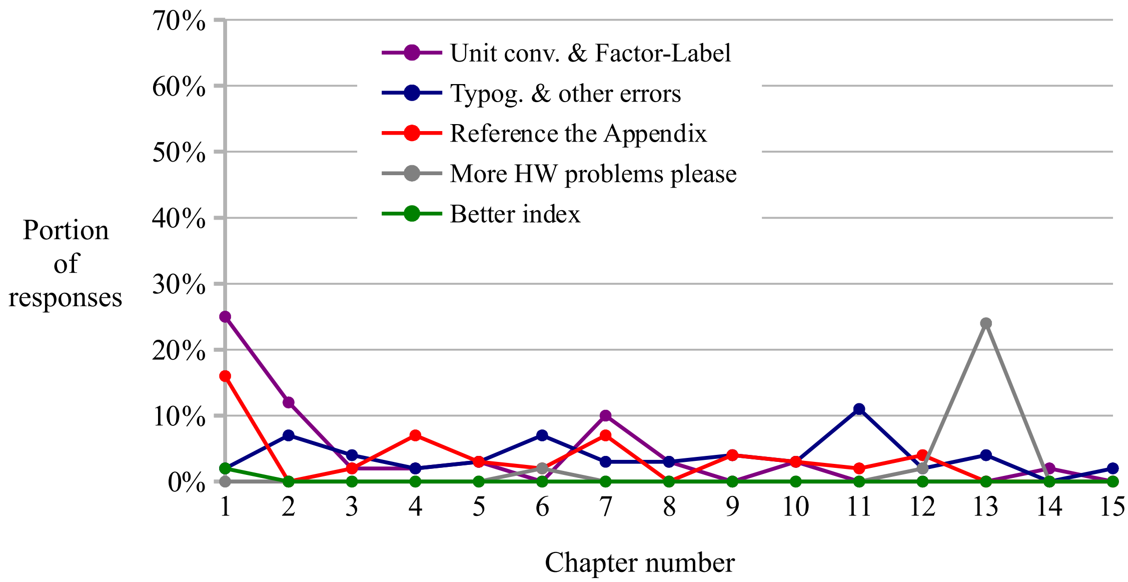

Figure 3: The percentage of responses in the last five categories was less than 4% each. This graph is show at the same vertical scale as Figure 2.

Response Length

The average response length was 34 words in Chapter 1; for the rest of the book the average length was about 23 words. Figure 4 shows that response lengths ranged from 3 to more than 100 words. Generally, the lengthier responses were detailed rather than chatty; for example, this response contains 105 words:

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?

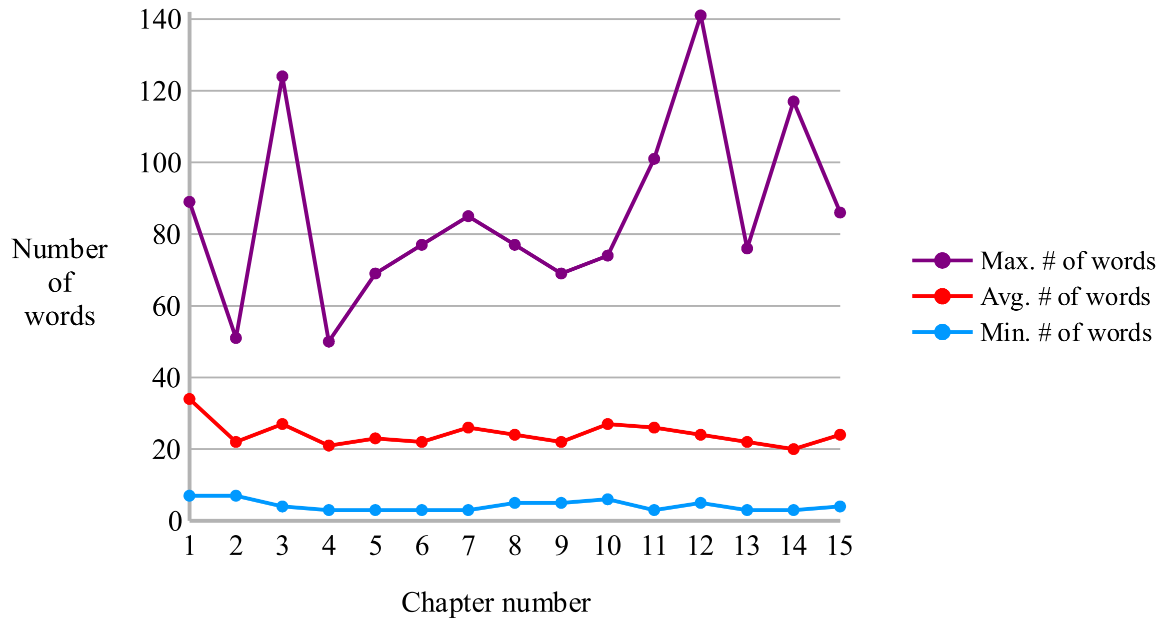

Figure 4: The average response length settled at about 23 words per response. This dataset does not include blank responses.

Some students were consistently more verbose than others. Figure 5 shows that the most verbose students earned the highest grades in the course. Most students fall in the upper left quadrant (fewer words, higher grades); no students fall in the lower right quadrant: (more words, lower grades).

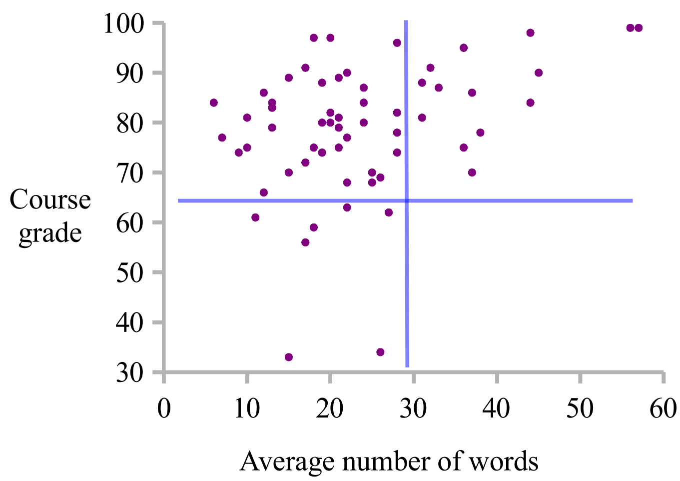

Figure 5: Course grade as a function of the average number of words written by each student. Each datapoint represents one student.

The passing grade in this course is 70%. In Figure 5, all of the failing students had fewer than 27 words per response on average, while passing students ranged as high as 57 words on average. In future, it would be interesting to explore whether the low word count in failing students represents a lower level of literacy, a lack of time to complete the assignment, a lack of comprehension, or a lack of interest.

Using the Feedback

The simplest way to use the feedback is to respond only to the most frequent comments (such as the request in Chapter 11 & 12 for problems in the other unit system). However, nearly four centuries ago, Galileo remarked:

> If reasoning were like hauling I should agree that several reasoners would be worth more than one, just as several horses can haul more sacks of grain than one can. But reasoning is like racing and not like hauling, and a single Barbary steed can outrun a hundred draft horses.[3]

Occasionally a single student has a unique idea that is transformative. The symbol for radius of gyration in this and many other mechanics textbooks is r (with respect to x and y axes, the symbols are r_x and r_y). One student remarked that r is also used for radius of a circle, and suggested r_G (r_{Gx}, r_{Gy}) would avoid confusion. This change was easy to implement.

The risk of making changes for *every* student response is that the book will become too long, and students will not want to read it. Rather than adding many new examples, I try to modify the existing examples to incorporate the requests. For example, one student suggested:

> Include a few more examples in Chapter 11 on beam design where when adding in the weight of the beam the maximum 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 existing example problem. Another student was confused by a homework problem referring 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; this oversight was easy to correct.

Did it Work?

The ultimate goal of this project was to improve the passing rate of students in *Strength of Materials*. Figure 6 shows the failure rate is now below 15%, down from a peak of 32%. There were no significant changes in admissions policies, staffing, or course content, so it appears that the new textbook has made a measurable difference in student performance.

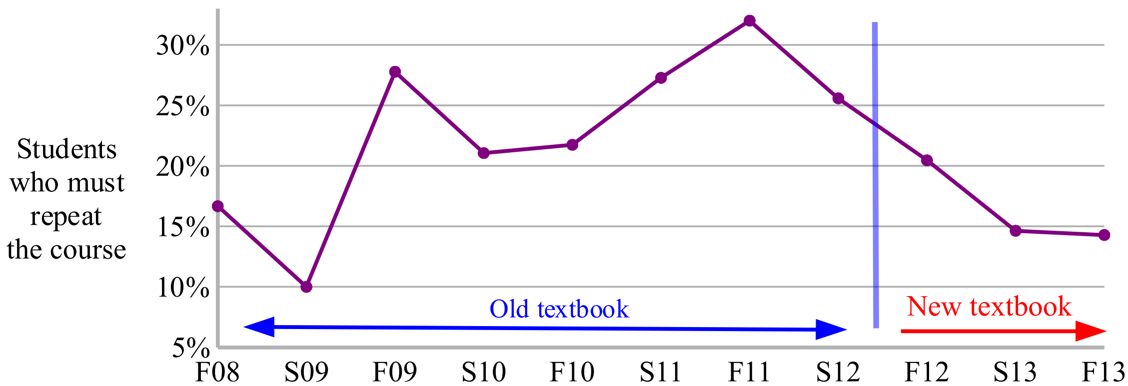

Figure 6: The new textbook was introduced in Fall 2012, coincident with a decline in failure rate that was already underway.

At the end of every semester, students are asked a series of questions about the course. One question asks their opinion of the textbook, on a 4-point Likert scale (excellent, good, fair, poor). The class averages in Figure 7 show a marked improvement in the semester that the textbook was introduced.

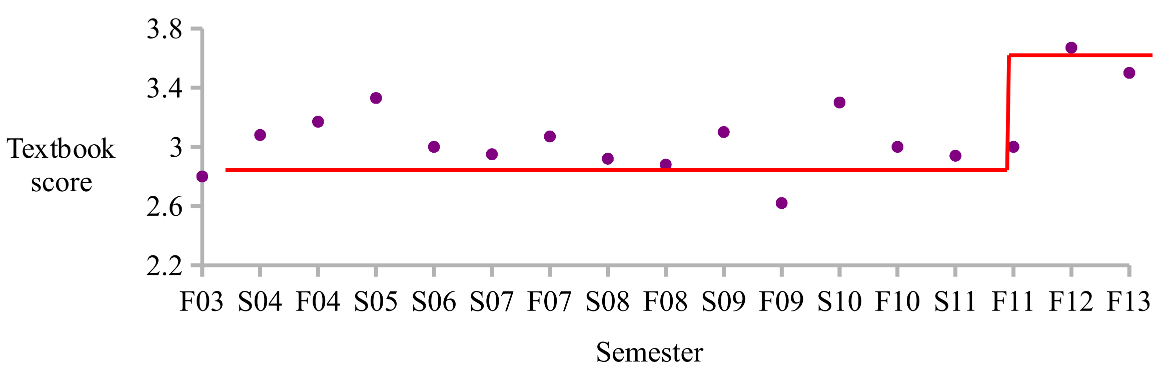

Figure 7: The score on the student survey question "Your Opinion of the Textbook: Excellent (4), Good (3), Fair (2), Poor (1)" shows a marked improvement after the new textbook was introduced.

This survey and other student feedback indicates that nearly all students like the new book (perhaps because it is free; perhaps because they have a hand in shaping it). Perhaps the most complimentary student response was:

Everything was clearly understandable. This is like a *Strength of Materials for Dummies* book, which is fine by me.

In writing the book, I used homework grades from previous semesters to identify topics that required extra explanation. The same approach is helpful in selecting topics to improve. The table below shows the class grades in each topic during the three semesters that the new book has been used, color coded into three categories: below 70%, 70% to 80%, and above 80%. The data indicate that more work needs to be done on beam design, beam stress, and properties of areas (i.e., calculating the moment of inertia of compound shapes), so I added examples and clarified the text in these sections of the book. Curiously, the list does not match student feedback; students said they found Mohr's circle to be the most difficult topic, and the chapter requiring the most improvement.

Grades in homework assignments over three semesters	**F12**	**S13**	**F13**
HW #23: Mohr's circle & stress visualization II	84	80	93
HW #22: Mohr's circle & stress visualization I	97	82	90
HW #19: Statically indeterminate beams	88	89	89
HW #2: Stress & strain	83	78	87
HW #11: Shear & moment diagrams II	78	79	87
HW #9: Beam reactions & load diagrams	85	84	85
HW #18: Combined stresses; short block	78	85	84
HW #6: Properties of areas I	84	80	82
HW #21: Columns II	78	77	82
HW #20: Columns I	80	71	81
HW #8: Torsion	82	90	78
HW #17: Combined stresses	76	77	78
HW #5: Bolted & welded joints	76	72	77
HW #10: Shear & moment diagrams I	71	68	77
HW #13: Bending & shear stresses in beams II	69	75	77
HW #4: Pressure vessels & stress concentrations	80	70	76
HW #14: Beam deflection	75	77	76
HW #1: Factor-label method of unit conversion	79	68	74
HW #3: Poisson's ratio & thermal expansion	73	66	74
HW #7: Properties of areas II	70	62	71
HW #12: Bending & shear stresses in beams I	77	72	70
HW #16: Steel & timber beam design II	59	65	67
HW #15: Steel & timber beam design I	72	48	56

Conclusions

In this project, students are active collaborators in textbook writing, not passive readers. Every student who participates in improving the textbook is listed as an editor in the preface. In the first class, I point out the improvements previous students have suggested, to show them that they have the power to improve the textbook. The continuous improvement process comprises these steps:

[1] Require students to provide feedback in sentence form.

[2] Provide written responses to feedback on the homework paper, as appropriate.

[3] Collate the student feedback in a spreadsheet.

[4] Analyze the types of responses (mostly “more examples” and “clarification” in this class).

[5] Review every response, and modify the textbook as appropriate.

[6] Monitor grades and pass rates over time to measure the effectiveness of the textbook changes.

Tailor-made textbooks available for free as pdf files can have a positive impact on student learning and student satisfaction. Involving the students as editors is also a sneaky way of getting students to read a textbook!

Student responses can also help to improve lectures, regardless of the type of textbook used. For example, I use a very good commercially-produced textbook in a freshman Engineering Materials class. I assign the “how would you improve” question in every homework assignment, then I bring answers to the next lecture. Conceptual responses like “I'm not sure what polar moment of inertia really is” or “what does a unit raised to the fourth power mean?” may be best addressed in class in a two-way conversation, rather than in the one-way conversation of a textbook.

[1] Barry Dupen, "How to Write a Textbook in Ten Easy Steps", Paper 6148, ASEE Annual Conference and Exposition, Atlanta, GA, June 23-26, 2013.
[2] http://www.etcs.ipfw.edu/~dupenb/ET_200
[3] Galileo Galilei, "The Assayer", 1621, quoted in Dava Sobel, *Galileo's Daughter,* Bloomsbury Publishing USA, 2009, p.93.