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An Inverted Teaching Model for a Mechanics of Materials Course

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AC 2012-4331: AN INVERTED TEACHING MODEL FOR A MECHANICS OF MATERIALS COURSE

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An Inverted Classroom Model
for a Mechanics of Materials Course

Abstract

Instructors at Missouri University of Science and Technology have been offering certain sections of a mechanics of materials course in an *inverted* format for the past two years. In this format, students learn the concepts outside of class, using a textbook, animations and videos developed by the authors, and work on homework either individually or in groups during the optional class time. Students take eight multiple-choice exams and a final exam that is common to both the inverted sections and the more traditional lecture-based sections. Homework in the inverted sections is assigned but not graded. The in-class exams are given in a computer lab, and each student receives an individualized set of questions.

Over 1200 students in 18 course sections have participated in either the inverted sections themselves or the other non-traditional sections that preceded the particular format used today. A subset of this group was compared to students in the traditional sections. No statistically significant difference between the two groups was found based on (1) performance on the common final exams or (2) course grade in a structural analysis course.

The animations and videos used by students in the inverted sections are available on a class web site. There are 167 animation modules and 230 videos. The animations contain example problems and exercises. The videos are, on average, six minutes in length and cover concepts, demonstrations, problem strategies, problem solutions, and experiments. The authors use Google Analytics to track how much each piece of content is utilized. The website was accessed 46,500 times, and the content, excluding the animations, was used for a total of 12,700 hours during the past 16 months.

By tracking how students perform on each multiple-choice question, the authors have developed a concept inventory with numerical rankings from the best to worst understood concepts. Combining this with how much each online resource is utilized, the authors can now target development of future course materials on the least-understood concepts and in the format most preferred by the students. An inverted teaching format would not be appropriate for every college course, but it has helped the authors begin looking at their mechanics of materials course in a more scientific, data-driven manner.

Introduction

Instructors at Missouri University of Science and Technology have experimented with the format of a Mechanics of Materials course since 2008. Table 1 summarizes these format changes, and a previous work[1] describes the evolution in detail. In the current *inverted* format, students learn the course concepts outside of the classroom, using a textbook, animations and videos developed by the authors, and work on homework either individually or in groups during the optional class time.

Semester	Students	Class Format
Fall 2002 – Spring 2008	275	traditional lectures
Summer 2008 – Fall 2008	195	videos replace lectures
Spring 2009 – Spring 2010	668	traditional lectures & videos
Summer 2010 – Fall 2011	405	inverted

Table 1. Summary of format changes for one instructor's classes.

Students are given the option of enrolling in the inverted sections taught by one instructor or more traditional sections taught by two other instructors. Students in the inverted sections take eight multiple-choice exams, and all of the students take a common, comprehensive multiple-choice final exam. The exams are given in a computer lab, and each student receives an individualized set of questions.

Homework in the inverted sections is assigned but not graded. Since most students have access to the solutions manual, the instructor of the inverted sections feels that exams are a more accurate indicator of student ability. However, he expects his students to do the homework and reference the solutions manual, or some other resource, when they cannot get correct answers. It is unlikely they will do well on the exams without thoroughly practicing the homework.

The authors have prepared over 2000 questions suitable for the multiple-choice format and divided them into 220 question categories. So far, 700 of these questions have been processed using Diploma, Respondus and Blackboard to create 6300 unique exam questions. A previous work[2] describes the question creation process in detail. Students are provided with a score on each of their exam questions and the class average for each question.

The animations and videos used by the students are modular in nature and available online. There are 167 animation modules and 230 videos. The animations contain example problems and exercises. The videos are, on average, six minutes in length and cover concepts, demonstrations, problem strategies, problem solutions, and experiments. Lesson notes, additional problem solutions, and old exams are also available to the students.

An inverted, or *flipped*, approach has used in a variety of engineering classes in recent years.[3-8] To the authors' knowledge this is the first time it has been used in a mechanics of materials course. With class attendance being optional and primarily devoted to homework, the degree to which the class is inverted may also be unique.

Effect of Format on Student Performance

The impact of format changes on the mean final-exam performance was examined in the first previous work mentioned above[1] and was found to not be statistically significant. However, the moderational role of ability was found to be significant. Students with higher GPAs often obtained higher final exam scores in the inverted format compared to the traditional format, whereas students with lower GPAs obtained higher scores in the traditional format than the inverted format. More details can be found in that work.

Previously published results only included data for sections taught by the instructor that currently uses the inverted format. More recently, a comparison was made between the sections taught by all three instructors. Class sections between Fall 2009 and Spring 2011 were combined to form two format conditions: Traditional (the two instructors' sections that still use a traditional format) and Inverted (the third instructor's sections that use the inverted format). Final exam scores served as the dependent variable. These conditions were compared in a one-way, between-subjects analyses of variance (ANOVA) with final exam score serving as the dependent variable. The ANOVA was not statistically significant. The means are displayed in Table 2.

An investigation into the impact of these same two format conditions on the class grade in the follow-on Structural Analysis course was also initiated. A preliminary comparison involving 84 students that took Structural Analysis during Fall 2010 and Fall 2011 showed no statistically significant difference. These means are also displayed in Table 2.

Performance Measure	Instructor/Format Condition	
	Instructors that Use Traditional Format in Mechanics of Materials	Instructor that Uses Inverted Format in Mechanics of Materials
Mean Score on Common Final Exam in Mechanics of Materials	67.5 (n = 513)	66.9 (n = 556)
Mean Class Grade in Structural Analysis	86.1 (n = 40)	86.5 (n = 44)

Table 2. Mean scores as a function of instructor and class format.

Google Analytics Data

The authors use Google Analytics (GA) to track how their online study aids are utilized by students in the inverted sections. The website for the inverted sections was visited 36,000 times, and the content, excluding the animations, was used for a total of 9,070 hours during 2011.

Appendix A shows screenshots of the GA interface. Figure A1 shows how frequently the web site was visited during 2011, visitor locations, and the type of content they accessed. 255 students took the inverted sections during 2011. There were 114 during the spring semester, 52 during the summer semester and 89 during the fall semester. The seven peaks on the left side of the graph correspond to the seven in-class exams (the eighth exam was canceled due to bad weather) and the final exam given during the spring semester. The peaks in the middle of the graph correspond to the exams given during the summer semester, and the peaks on the right side of the graph correspond to exams given during the fall semester. Figures A2 and A3 map visitor location around the world and the United States, respectively.

While the web site usage is anonymous, i.e. no login is required, GA places a cookie on the user's computer to measure how often that user/device combination comes back to the site. The authors are confident that usage by students in the traditional sections is small because there is no observable increase in usage that corresponds to their exam days.

To get a better indication of usage by their own students, the authors often filter out the out-of-state data but retain all of the in-state data, because students often travel home on the weekends and study from there and one of the instructors is stationed at another campus in the state. The usage maps appear to support this hypothesis, with higher usage levels coming from the cities closer to the main campus. The maps show little to no usage coming from students at the in-state university with the next largest enrollment of engineering students (the authors' campus has the largest enrollment).

Figure A7 shows a usage summary based on page title. By indicating the type of content contained in a web page through its page title, the authors can easily filter the usage data to see how students use the different types of content as the semester progresses. Figure 1 shows usage trends for six types of content during the fall semester of 2011. These content items are described in detail in a previous work.[1]

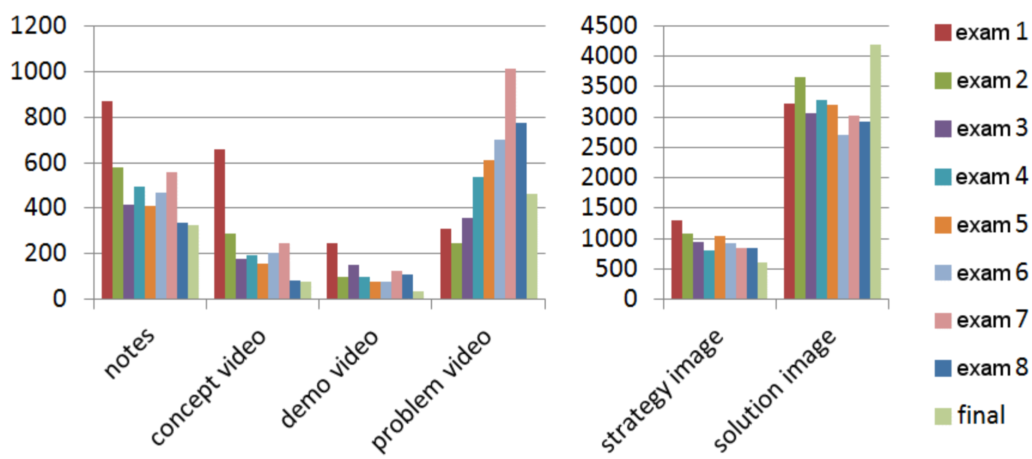

Figure 1. Summary of content usage for each exam during the fall semester of 2011 (values are pageviews).

The most commonly accessed content item is the handwritten homework solutions prepared by the instructor, followed by the homework strategy pages—partial solutions emphasizing the solution process instead of the exact equation and numbers needed to solve the problem. It has been observed over multiple semesters that the students shift their usage to the problem-solution videos away from all the other types of content as the semester progresses. An exception to this occurs just prior to the final exam, where the students shift their attention back to the instructor's handwritten homework solutions.

Usage for items other than study aids, such as course policies, is also tracked. Figure 2 shows how often students accessed the class schedule, policies, frequently-asked-questions, average section grades, old quizzes, and chapter pages during the fall of 2011. The schedule and chapter pages are the primary navigation routes through the web site. The class schedule is included in the root of the web site, so most students begin there, navigate to the desired chapter page, and then access the study aids associated with that chapter. As seen in lower half of Figure 2, students focused on the two or three chapters associated with each exam and then spread their attention to all of the chapters as they prepared for the comprehensive final exam.

	Exam 1	Exam 2	Exam 3	Exam 4	Exam 5	Exam 6	Exam 7	Exam 8	Final Exam
schedule	2512	1943	1469	1770	1647	1665	1482	1414	1371
policies	80	37	25	19	24	21	26	44	23
faq	29	19	6	3	10	12	10	66	58
grades	66	327	261	184	254	267	177	183	303
quizzes	407	447	316	229	144	191	285	179	368
chapter 01	2673	328	41	31	25	30	47	84	319
chapter 02	1645	428	12	10	21	10	17	60	298
chapter 03	1142	371	8	14	22	21	14	42	204
chapter 04	27	1420	200	13	26	6	21	27	192
chapter 05	37	2256	587	56	60	24	27	44	501
chapter 06	15	11	2367	559	90	21	42	25	494
chapter 07	42	16	710	190	30	16	23	12	111
chapter 08	55	22	78	2357	544	36	69	43	356
chapter 09	22	26	6	909	1460	187	109	80	294
chapter 10	9	8	8	42	1923	573	87	33	247
chapter 11	32	13	13	19	43	1646	295	30	125
chapter 12	12	22	14	2	31	1501	693	161	216
chapter 13	1	6	4	5	4	22	2107	448	167
chapter 14	7	3	1	7	0	6	770	471	158
chapter 15	9	6	4	6	11	7	61	2298	1150

Figure 2. Navigation trends during the fall semester of 2011 (values are pageviews).

Performance Index

The authors have experimented with multiple-choice exams since the summer of 2008, and the performance on each question has been documented since the fall semester of 2009. Since then, 813 students have taken multiple-choice in-class exams, and 1394 students have taken common, comprehensive, multiple-choice final exams. Only the students in the inverted sections took the multiple-choice in-class exams. Students in the traditional sections took open-response exams. All of the students took the multiple-choice final exams.

The authors have thus far created 700 *root* multiple-choice questions, with approximately 12 variations of each question, and sorted the questions into 220 question categories. The variations make it difficult for students to cheat by looking at a neighbor's exam. Calculation questions are varied by changing the numbers in the problem statement. Concept questions are varied by changing the image associated with the problem statement. The question categories have been tied to 132 enabling learning objectives.

Since the fall semester of 2009, 425 root questions covering 145 categories have been used on exams. Table 3 summarizes how many of these questions were used on the in-class exams versus final exams. In total, 122,790 student responses have been documented.

	In-Class Exams	Final Exams
Students	813	1394
Sections	9	20
Semesters	7	7
Question Categories	145	71
Root Questions	429	147
Graded Questions	84,651	38,139

Table 3. Multiple-choice exam usage during 2009-2011.

By tracking how students perform on each multiple-choice question and then filtering the questions by category, the authors have developed a concept inventory with numerical rankings from the best to worst understood concepts.

Exam difficulty can varied widely depending on how many questions are given, how much time is allowed, what topics are covered on the exam, etc. To assess how well students performed on an individual question independently from how easy or how difficult the entire exam was, a *performance index* (PI) was defined as the mean for the question divided by the mean for the exam. A PI equal to 1 would indicate an average understanding for that concept, a PI greater than 1 would indicate an above-average understanding, and a PI less than 1 would indicate a below-average understanding. This definition was chosen for its simplicity and ease of implementation.

$$Performance\ Index = \frac{Root\ Question\ Mean}{Exam\ Mean}$$

The PI for each root question was weighted, based on how many students worked the question, to determine a combined PI for each question category, each chapter and each of the eight in-class exams, or, more accurately, for the collection of topics spanned by each exam.

$$Combined\ Performance\ Index = \frac{\sum\left(\frac{Root\ Question\ Mean}{Exam\ Mean} \times Graded\ Questions\right)_i}{\sum\left(Graded\ Questions\right)_i}$$

The PI for each question category is contained in Appendix B. Tables B1 through B15 correspond to Chapter 1 through 15. To give a better understanding of how robust each PI may or may not be, the number of root questions, graded questions (or student responses), and exams the questions were used in are provided. A PI based on one root question would not be as trustworthy as one with four or more root questions. That one root question may have been uniquely tougher or easier than other, as yet unasked, questions in that category. Over time the authors hope to increase the diversity of questions that comprise the PI in each category.

Combining performance data with how much each online resource is utilized, the authors hope to target future course materials on the least-understood concepts and in the format most preferred by the students. Table 4 provides the average content usage per student and the PI for each chapter of the author's textbook. The number of categories, root questions and graded questions used in determining each PI value are provided in the table.

Chapter	Online Content Usage per Student (minutes)	Performance Index (1 = average)	Question Categories	Root Questions	Graded Questions
1. Stress	128	1.14	15	25	8,656
2. Strain	86	1.02	6	16	5,412
3. Mechanical properties	63	0.98	10	33	4,816
4. Design concepts	87	1.00	6	9	2,594
5. Axial deformation	150	0.98	13	17	6,330
6. Torsion	201	0.94	13	32	10,857
7. Equilibrium of beams	37	1.13	11	28	5,934
8. Bending	165	1.07	10	30	10,998
9. Shear stress in beams	134	0.90	7	25	10,007
10. Beam deflections	131	0.98	12	54	14,293
11. Statically indeterminate beams	103	0.81	6	19	4,514
12. Stress transformations	107	1.13	13	42	12,346
13. Strain transformations	129	1.05	10	37	9,833
14. Thin-walled pressure vessels	49	0.89	6	24	8,520
15. Combined loads	183	0.85	7	38	7,680

Table 4. Summary of web site usage per student and the associated performance index for each chapter.

Figure 3 provides a visual comparison of the PI per chapter. As one would expect, the first chapter has the highest PI. That would probably be true of any textbook. Chapters 7, which covers shear-force and bending-moment diagrams, has a high PI but the lowest amount of student usage. This is not surprising since the topic is covered in the statics course taken immediately prior to the mechanics of materials course. Chapter 12, which covers stress transformations, is also highly ranked. Chapters 11 and 15, which cover statically-indeterminate beam deflection and combined loads, respectively, have the lowest PI.

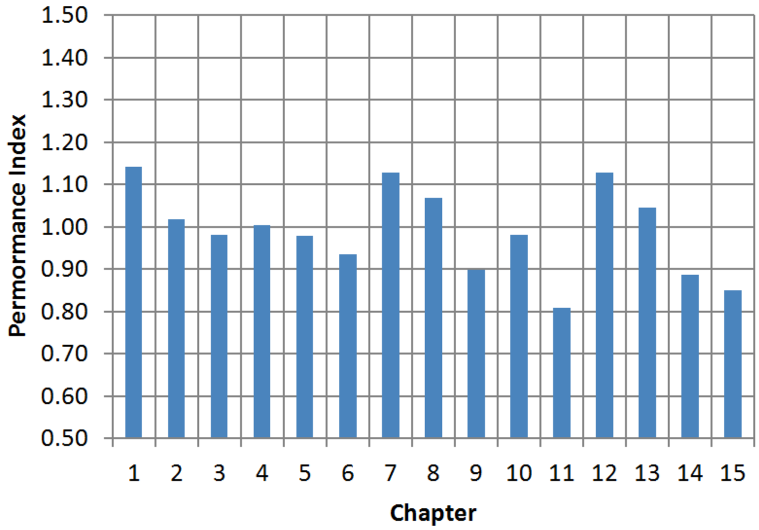

Figure 3. Performance index for each chapter.

Table 5 contains the average content usage per student per class period and the combined PI associated with each exam. Figure 4 visually compares the PI for each exam. Exams 1 and 6 have the highest PI. Interestingly, Exam 8 has the lowest PI but the highest amount of student content usage. Combined loads is typically the only topic covered on that exam.

Exam	Chapters Covered	Web Site Usage per Student per Class Period (minutes)	Performance Index (1 = average)	Question Categories	Root Questions	Graded Questions
1	1, 2, 3	50	1.07	31	74	18,884
2	4, 5	49	0.99	19	26	8,924
3	6, 7	47	1.00	24	60	16,791
4	8, 9	48	0.99	16	47	17,319
5	9, 10	54	0.99	13	62	17,979
6	11, 12	50	1.04	19	61	16,860
7	13, 14	50	0.97	16	61	18,353
8	15	55	0.85	7	38	7,680

Table 5. Summary of web site usage per student per class period and the associated performance index for each exam.

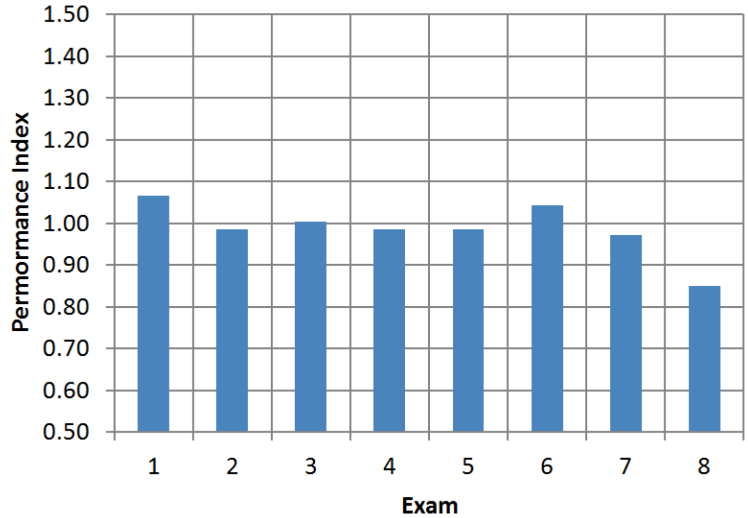

Figure 4. Performance index for each in-class exam.

All 145 question categories, as they occur during the semester, are plotted in Figure 5. Chapter 1 categories appear on the far left, and Chapter 15 categories appear on the far right. It is interesting to note the wide range of PI values throughout the semester. Figure 6 shows a histogram for the information presented in Figure 5.

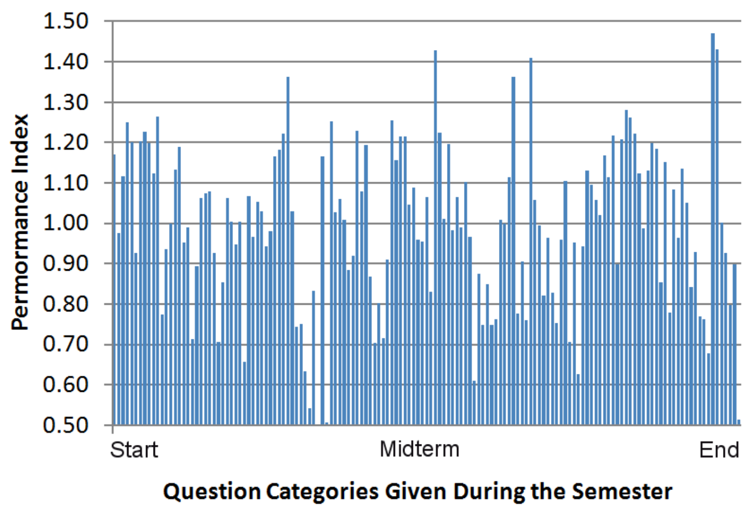

Figure 5. Performance index for each question category used from the start of the semester (left) to the end of the semester (right).

The categories, sorted from the highest PI to the lowest PI, are listed in Appendix C. It is not surprising that most of the concepts that involve only statics have above-average performance, while the statically-indeterminate concepts are all near the bottom. The authors hope to further refine the ranked list. Some of the same concepts are covered in multiple chapters, so it might be fruitful to combine their categories. Doing so would condense the list and perhaps make it more digestible.

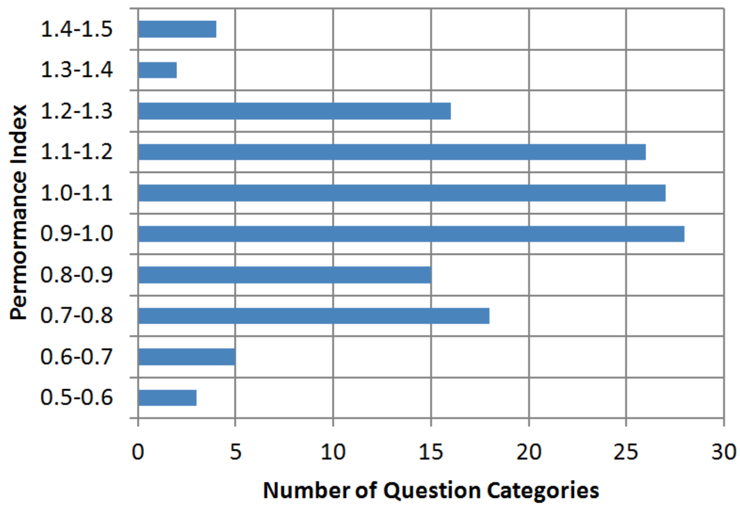

Figure 6. Performance index histogram.

Conclusions

The authors have put much effort into redesigning a mechanics of materials course. They have attempted to maintain the quality of instruction while building an efficient, data-rich teaching and learning environment. Now with the ability to measure student performance on almost every topic plus how the students utilize the provided study materials, the authors are ready to shift their focus to improving the quality of instruction. They intend to make targeted improvements to their study materials and observe the impact on student performance and usage.

An inverted teaching format would not be appropriate for every college course nor every college student, but the inverted format used at Missouri University of Science and Technology has an appealing level of flexibility for both the instructor and the students. Once the infrastructure has been developed, the instructor can focus on data analysis and getting to know the students instead of grading large stacks of paper. The students can study in a variety of ways and select the method that best suits their learning style.

This effort has been challenging and a bit overwhelming at times, but the authors see much potential in learning analytics. Providing students with individualized performance dashboards in order to visualize and manage their progress through the course is now a possibility. Perhaps many students could act upon immediate remediation advice instead of getting overwhelmed and having to repeat the course?

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Appendix A – Google Analytics Screenshots

Jan 1, 2011 - Dec 31, 2011

Visits

Visits	Unique Visitors	Time on Site	Avg. Time on Site	Pageviews	Pages/Visit
36,029	7,940	9070:16:59	00:15:06	333,355	9.25
% of Site Total: 100.00%	% of Site Total: 100.00%	% of Site Total: 100.00%	Site Avg: 00:15:06 (0.00%)	% of Site Total: 100.00%	Site Avg: 9.25 (0.00%)

	Continent None	Visits	Unique Visitors	Time on Site	Avg. Time on Site	Pageviews	Pages/Visit
1.	Americas	32,664	5,494	8850:29:37	00:16:15	313,353	9.59
2.	Asia	2,060	1,491	143:04:05	00:04:10	13,532	6.57
3.	Europe	635	520	22:16:53	00:02:06	2,600	4.09
4.	Oceania	465	275	41:06:50	00:05:18	2,937	6.32
5.	Africa	148	138	10:18:35	00:04:11	588	3.97

	Page Title None	Time on Page	Avg. Time on Page	Pageviews	Unique Pageviews	Unique Visitors
1.	Problem Solution	3943:24:30	00:02:47	94,180	76,998	2,448
2.	Problem Solution Video	1059:33:30	00:05:28	13,365	11,765	1,030
3.	Lecture Notes	992:57:20	00:00:43	90,569	27,461	4,712
4.	Problem Strategy	968:28:17	00:02:57	21,050	16,407	1,306
5.	IDE 110 | Thomas | Schedule	751:51:04	00:01:16	44,822	24,580	4,565
6.	Concept Video	404:54:12	00:04:49	5,715	5,292	884
7.	IDE 110 | Thomas | Quizzes	213:50:51	00:02:04	7,790	2,972	1,177

Figure A1. Google Analytics dashboard showing a summary of web site usage during 2011.

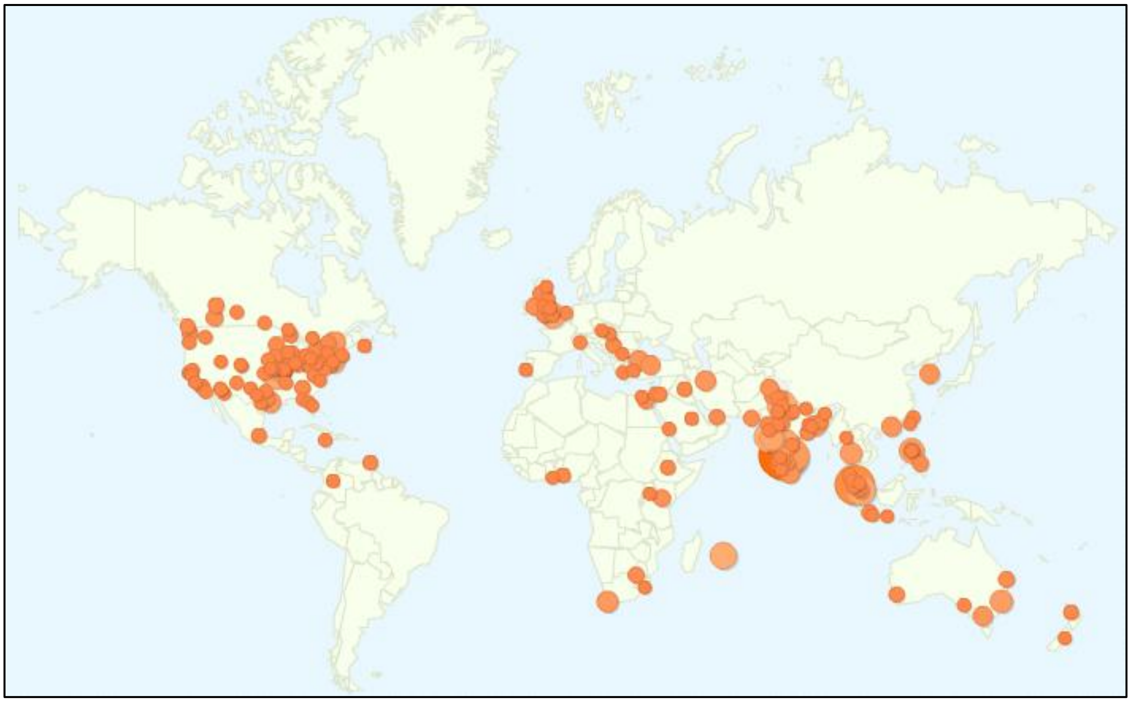

Figure A2. Google Analytics map showing user locations during 2011.

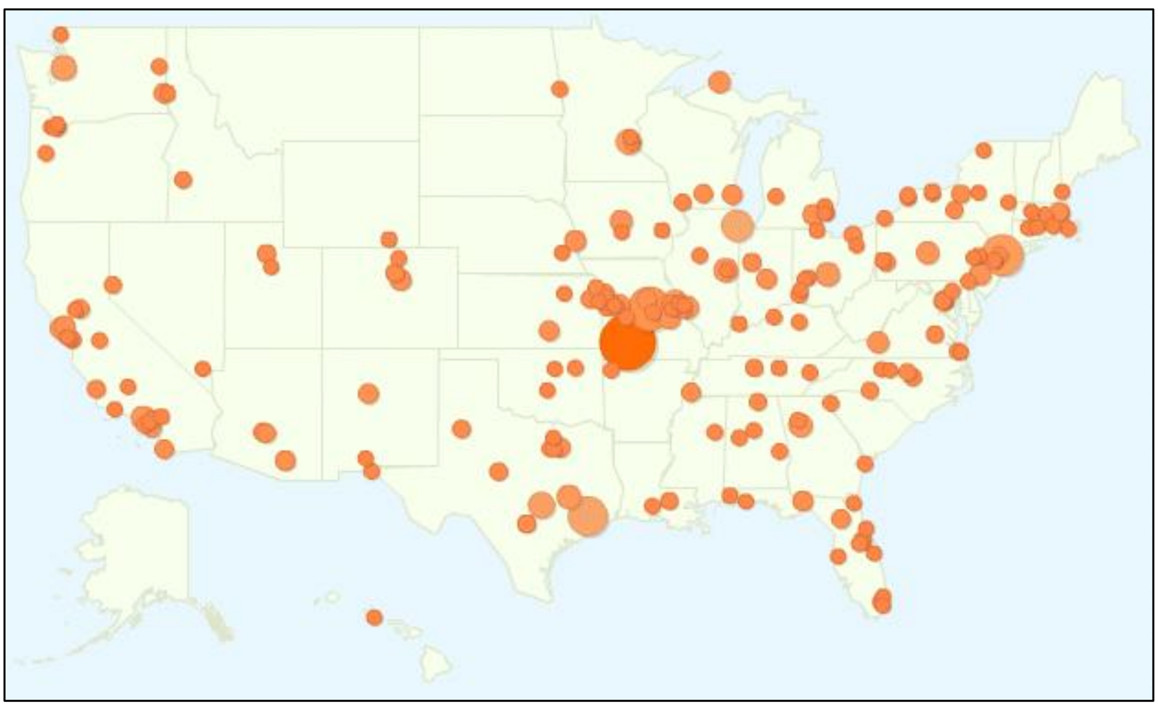

Figure A3. Google Analytics map showing user locations in the United States during 2011.

Appendix B – Question Categories Sorted by Chapter

<table>
<tr><th colspan="4">Question Category</th><th>Performance Index</th><th>Root Questions</th><th>Graded Questions</th><th>Exams</th></tr>
<tr><td rowspan="2">summation of forces</td><td rowspan="2">1.10</td><td colspan="2">one direction</td><td>1.17</td><td>2</td><td>502</td><td>4</td></tr>
<tr><td colspan="2">two directions</td><td>0.98</td><td>2</td><td>311</td><td>3</td></tr>
<tr><td colspan="4">summation of moments</td><td>1.12</td><td>3</td><td>589</td><td>5</td></tr>
<tr><td colspan="4">normal stress</td><td>1.25</td><td>1</td><td>675</td><td>6</td></tr>
<tr><td rowspan="2">summation of forces & normal stress</td><td rowspan="2">1.13</td><td colspan="2">one direction</td><td>1.20</td><td>3</td><td>1223</td><td>9</td></tr>
<tr><td colspan="2">two directions</td><td>0.93</td><td>2</td><td>415</td><td>3</td></tr>
<tr><td colspan="4">normal stress & summation of moments</td><td>1.20</td><td>1</td><td>529</td><td>3</td></tr>
<tr><td rowspan="5">direct shear stress</td><td rowspan="5">1.17</td><td rowspan="2">bolts or pins</td><td>single shear</td><td>1.23</td><td>2</td><td>867</td><td>5</td></tr>
<tr><td>double shear</td><td>1.20</td><td>3</td><td>1045</td><td>8</td></tr>
<tr><td rowspan="2">glued joints</td><td>plates</td><td>1.12</td><td>1</td><td>630</td><td>5</td></tr>
<tr><td>pipes</td><td>1.26</td><td>1</td><td>510</td><td>3</td></tr>
<tr><td colspan="2">punch</td><td>0.77</td><td>1</td><td>278</td><td>2</td></tr>
<tr><td colspan="4">summation of moments & direct shear stress on key</td><td>0.94</td><td>1</td><td>224</td><td>2</td></tr>
<tr><td colspan="4">bearing stress, with flat contact surfaces</td><td>1.00</td><td>1</td><td>443</td><td>5</td></tr>
<tr><td colspan="4">normal stress & bearing stress</td><td>1.13</td><td>1</td><td>415</td><td>3</td></tr>
</table>

Table B1. Question categories for Chapter 1 – Stress.

<table>
<tr><th colspan="3">Question Category</th><th>Performance Index</th><th>Root Questions</th><th>Graded Questions</th><th>Exams</th></tr>
<tr><td rowspan="4">normal strain</td><td rowspan="4">1.06</td><td>co-axial</td><td>1.19</td><td>3</td><td>1514</td><td>9</td></tr>
<tr><td>co-axial with gap</td><td>0.95</td><td>1</td><td>278</td><td>2</td></tr>
<tr><td>rotating bar</td><td>0.99</td><td>1</td><td>821</td><td>6</td></tr>
<tr><td>rotating bar with gap</td><td>0.71</td><td>2</td><td>311</td><td>3</td></tr>
<tr><td colspan="3">shear strain</td><td>0.89</td><td>5</td><td>1356</td><td>8</td></tr>
<tr><td colspan="3">thermal strain</td><td>1.06</td><td>4</td><td>1132</td><td>9</td></tr>
</table>

Table B2. Question categories for Chapter 2 – Strain.

<table>
<tr><th colspan="3">Question Category</th><th>Performance Index</th><th>Root Questions</th><th>Graded Questions</th><th>Exams</th></tr>
<tr><td colspan="3">Hooke's law</td><td>1.08</td><td>3</td><td>1036</td><td>7</td></tr>
<tr><td colspan="3">Poisson's ratio</td><td>1.08</td><td>3</td><td>1290</td><td>7</td></tr>
<tr><td colspan="3">Hooke's law & Poisson's ratio</td><td>0.93</td><td>1</td><td>260</td><td>2</td></tr>
<tr><td colspan="3">shear modulus</td><td>0.71</td><td>2</td><td>415</td><td>3</td></tr>
<tr><td rowspan="6">stress-strain curve</td><td rowspan="6">0.93</td><td>Young's modulus</td><td>0.85</td><td>4</td><td>347</td><td>3</td></tr>
<tr><td>proportional limit</td><td>1.06</td><td>4</td><td>275</td><td>3</td></tr>
<tr><td>yield strength</td><td>1.00</td><td>4</td><td>347</td><td>3</td></tr>
<tr><td>ultimate strength</td><td>0.95</td><td>4</td><td>347</td><td>3</td></tr>
<tr><td>fracture strength</td><td>1.00</td><td>4</td><td>275</td><td>3</td></tr>
<tr><td>true fracture strength</td><td>0.66</td><td>4</td><td>224</td><td>2</td></tr>
</table>

Table B3. Question categories for Chapter 3 – Mechanical Properties.

<table>
<tr><th colspan="3">Question Category</th><th>Performance Index</th><th>Root Questions</th><th>Graded Questions</th><th>Exams</th></tr>
<tr><td colspan="3">summation of moments</td><td>1.07</td><td>1</td><td>88</td><td>1</td></tr>
<tr><td colspan="3">summation of forces and moments</td><td>0.97</td><td>1</td><td>88</td><td>1</td></tr>
<tr><td rowspan="4">factor of safety</td><td rowspan="4">1.00</td><td>definition</td><td>1.05</td><td>1</td><td>217</td><td>2</td></tr>
<tr><td>stress</td><td>1.03</td><td>2</td><td>1315</td><td>9</td></tr>
<tr><td>statics & stress</td><td>0.94</td><td>3</td><td>669</td><td>7</td></tr>
<tr><td>stress & choose best answer</td><td>0.98</td><td>1</td><td>217</td><td>2</td></tr>
</table>

Table B4. Question categories for Chapter 4 – Design Concepts.

Question Category			Performance Index	Root Questions	Graded Questions	Exams
summation for forces, one direction			1.17	1	265	3
summation of moments			1.18	1	265	3
stress & deformation & choose best answer			1.22	1	217	2
deformation			1.36	2	1713	12
statics & deformation			1.03	2	1455	10
indeterminate deformation	0.70	coaxial	0.74	2	407	3
		end-to-end	0.75	1	298	3
		rotating bar	0.63	1	88	1
		rotating bar with gap	0.54	1	190	1
free thermal expansion			0.83	1	88	1
indeterminate thermal deformation	0.54	coaxial	0.47	1	617	5
		end-to-end with one material	1.17	1	88	1
		end-to-end with two materials	0.51	2	639	4

Table B5. Question categories for Chapter 5 – Axial Deformation.

Question Category			Performance Index	Root Questions	Graded Questions	Exams
summation of torques			1.25	1	87	2
stress			1.03	2	270	3
summation of torques & stress			1.06	4	621	6
deformation			1.01	3	576	5
summation of torques & deformation			0.88	1	778	4
choose the best answer			0.92	3	1631	10
summation of torques & gears (speed or angle)			1.23	5	1585	9
summation of torques & gears & deformation			1.08	1	222	2
power & gears			1.19	2	457	3
power & deformation			0.87	1	1116	6
summation of torques & power & deformation			0.70	2	853	7
indeterminate torsion	0.77	concentric	0.80	3	1544	10
		end-to-end	0.72	4	1117	9

Table B6. Question categories for Chapter 6 – Torsion.

Question Category			Performance Index	Root Questions	Graded Questions	Exams
ground reactions	1.21	simply supported, find one side	0.91	1	87	1
		simply supported, find both sides	1.25	3	629	3
		cantilever	1.16	5	1189	7
max shear force	1.21	simply supported	1.21	5	969	4
		cantilever	1.22	1	222	3
shear force at particular location, simply supported			1.05	2	357	4
max moment	1.09	simply supported	1.09	7	2076	11
		cantilever	0.96	1	48	1
max moment location	0.99	simply supported	0.95	1	87	1
		cantilever	1.07	1	48	1
moment at particular location, simply supported			0.83	1	222	2

Table B7. Question categories for Chapter 7 – Equilibrium of Beams.

Question Category			Performance Index	Root Questions	Graded Questions	Exams
centroid			1.43	3	1249	9
moment of inertia			1.22	4	1524	9
stress	1.08	symmetric beam	1.01	7	1800	5
		non-symmetric beam	1.20	3	1892	12
		V&M, cantilever beam	0.98	2	1080	4
		V&M, simply-supported shaft	1.07	1	824	5
composite beam	0.98	symmetric, moment of inertia	0.99	1	268	3
		symmetric, stress	1.10	1	88	1
		non-symmetric, centroid	0.97	2	935	5
combined loading			0.61	6	1338	7

Table B8. Question categories for Chapter 8 – Bending.

Question Category			Performance Index	Root Questions	Graded Questions	Exams
rectangular	0.86	V&M, cantilever, stress	0.87	4	2748	5
		V&M, simply-supported, stress	0.75	1	313	4
circular	0.82	V&M, simply-supported solid, stress	0.85	2	704	4
		V&M, cantilever pipe, stress	0.75	1	268	3
flanged	0.82	I-beam, stress	0.76	8	1731	9
		channels & tees, stress	1.01	1	557	4
shear flow in built-up beam			1.00	8	3686	14

Table B9. Question categories for Chapter 9 – Shear Stress in Beams.

Question Category			Performance Index	Root Questions	Graded Questions	Exams
integration	1.05	boundary conditions, overhung	1.11	8	2981	6
		boundary conditions, cantilever	1.36	6	1530	4
		distributed load equation	0.78	2	350	1
		shear force or bending moment equation	0.91	5	1445	3
		slope equation	0.76	5	1210	2
		slope at particular location	1.41	1	85	1
		deflection at particular location	1.06	1	85	1
		deflection equation	0.99	5	1071	3
superposition	0.88	simply supported	0.82	6	1348	9
		cantilever	0.96	9	2252	10
		overhung	0.83	4	1510	8
		doubly overhang	0.75	2	426	2

Table B10. Question categories for Chapter 10 – Beam Deflections.

Question Category			Performance Index	Root Questions	Graded Questions	Exams
value forced to zero	1.08	simply supported with deflection forced to zero	0.96	1	82	1
		cantilever with slope forced to zero	1.10	2	412	2
three supports			0.71	3	1300	10
propped cantilever			0.95	7	1446	7
movable support	0.65	simply supported	0.63	5	1192	6
		cantilever	0.94	1	82	1

Table B11. Question categories for Chapter 11 – Statically Indeterminate Beams.

Question Category			Performance Index	Root Questions	Graded Questions	Exams
inclined plane	1.08	normal stress	1.13	1	82	1
		shear stress	1.10	2	537	4
		normal and shear stress	1.06	1	613	4
principal s and max shear from transformation equations	1.07	principal stresses	1.02	9	3729	11
		max shear stress	1.17	5	1318	10
		absolute max shear stress	1.11	5	1033	3
read Mohr's circle	1.17	x-y stresses	1.22	5	1593	9
		principals	0.90	3	335	4
		max shear	1.21	3	335	4
draw Mohr's circle and find values	1.25	principals and max shear	1.28	3	1582	11
		principals, sketch stress element	1.26	2	174	3
		principals and max shear, sketch stress element	1.22	1	762	4
		absolute max shear	1.12	2	253	3

Table B12. Question categories for Chapter 12 – Stress Transformations.

Question Category	Performance Index	Root Questions	Graded Questions	Exams
strain along diagonal	0.99	5	1518	9
principal and max shear strains	1.13	4	1376	9
sketch strain element	1.20	1	83	1
principal and max shear strains using Mohr's circle	1.18	12	2290	10
strains from strain gages	0.85	6	1849	5
max shear strain from strain gages	1.15	2	477	3
principal orientation from strain gages	0.78	1	399	3
Hooke's law, change in length	1.08	4	1717	9
Hooke's law, change in thickness	0.96	1	83	1
Hooke's law, stresses from strain gages	1.14	1	41	1

Table B13. Question categories for Chapter 13 – Strain Transformations.

<table>
<tr><th colspan="3">Question Category</th><th>Performance Index</th><th>Root Questions</th><th>Graded Questions</th><th>Exams</th></tr>
<tr><td rowspan="2">sphere</td><td rowspan="2">0.98</td><td>stress</td><td>1.05</td><td>4</td><td>2728</td><td>11</td></tr>
<tr><td>strain</td><td>0.84</td><td>3</td><td>1445</td><td>10</td></tr>
<tr><td rowspan="4">cylinder</td><td rowspan="4">0.80</td><td>stress</td><td>0.93</td><td>8</td><td>1598</td><td>8</td></tr>
<tr><td>strain</td><td>0.77</td><td>3</td><td>1231</td><td>9</td></tr>
<tr><td>change in dimension</td><td>0.76</td><td>1</td><td>83</td><td>1</td></tr>
<tr><td>welded cylinder</td><td>0.68</td><td>5</td><td>1435</td><td>8</td></tr>
</table>

Table B14. Question categories for Chapter 14 – Thin-Walled Pressure Vessels.

Question Category	Performance Index	Root Questions	Graded Questions	Exams
shaft with normal force & torque	1.47	1	180	1
shaft with normal force & multiple torques	1.43	3	257	3
cross section with normal force, shear force and bending moment	1.00	7	1257	7
simply supported beam	0.93	1	155	1
rectangular post	0.80	12	3412	15
cylindrical post	0.90	9	1371	8
pressurized pipe	0.51	5	1048	7

Table B15. Question categories for Chapter 15 – Combined Loads.

Appendix C – Question Categories Sorted by Performance Index

Chpt	Problem Category	Statics Only?	Performance Index	Root Questions	Graded Questions	Exams
15	shaft with N & T		1.47	1	180	1
15	shaft with N and multiple T		1.43	3	257	3
8	centroid	yes	1.43	3	1249	9
10	integration, find slope at spot		1.41	1	85	1
5	deformation		1.37	2	1704	12
10	integration, boundary conditions, cantilever		1.36	6	1530	4
12	draw Mohr's circle, principals and max shear		1.28	3	1573	11
1	direct shear stress, glued joints, pipes		1.26	1	510	3
12	draw Mohr's circle, principals & sketch stress element		1.26	2	174	3
7	ground reactions, simply supported, both sides	yes	1.25	3	629	3
6	summation of torques	yes	1.25	1	87	2
1	normal stress		1.25	1	675	6
6	summation of torques & gears (speed or angle)		1.23	5	1585	9
8	moment of inertia	yes	1.22	4	1524	9
5	deformation & stress & choose best answer		1.22	1	217	2
1	direct shear stress, bolts & pins, single shear		1.22	2	858	5
12	read Mohr's circle, x-y stresses		1.22	5	1593	9
7	find max V, cantilever	yes	1.22	1	222	3
7	find max V, simply supported	yes	1.21	5	969	4
12	read Mohr's circle, max shear		1.21	3	335	4
12	draw Mohr's circle, principals and max shear & sketch		1.21	1	753	4
1	normal stress, summation of moments		1.20	1	529	3
1	direct shear stress, bolts & pins, double shear		1.20	3	1045	8
13	draw sketch of strain element		1.20	1	83	1
6	power & gears		1.19	2	457	3
2	normal strain, co-axial		1.19	3	1505	9
8	normal stress, non-symmetric beam		1.19	3	1883	12

Table C1. Question categories sorted by performance index.

1	normal stress, summation of forces, one direction		1.19	3	1214	9
13	principal and max shear strains using Mohr's circle		1.18	12	2290	10
5	summation of moments	yes	1.18	1	265	3
1	summation of forces, one direction	yes	1.17	2	502	4
12	principals and max shear from transformation equations, max shear stress		1.17	5	1318	10
5	indeterminate thermal, end-to-end (one material)		1.17	1	88	1
5	summation for forces, one direction	yes	1.17	1	265	3
7	ground reactions, cantilever	yes	1.16	5	1189	7
13	max shear strain		1.15	2	477	3
13	stresses from strain gages		1.14	1	41	1
13	principal and max shear strains		1.13	4	1367	9
1	bearing stress & normal stress		1.13	1	415	3
12	inclined plane, normal stress		1.13	1	82	1
1	direct shear stress, glued joints, plate		1.12	1	630	5
12	draw Mohr's circle, absolute max shear		1.12	2	253	3
1	summation of moments	yes	1.12	3	589	5
10	integration, boundary conditions, overhung		1.11	8	2981	6
12	principals and max shear from transformation equations, absolute max shear stress		1.11	5	1033	3
8	normal stress, V&M, simply-supported shaft		1.11	1	815	5
11	value forced to zero, cantilever with slope forced to zero		1.10	2	412	2
8	composite beam, symmetric, normal stress		1.10	1	88	1
12	inclined plane, shear stress		1.10	2	537	4
7	max M, simply supported	yes	1.09	7	2076	11
13	Hooke's law, find change in length		1.09	4	1708	9
6	summation of torques & gears & stress		1.08	1	222	2
3	Hooke's law		1.08	3	1036	7
9	flanged, shear stress, channels and tees		1.07	1	548	4
4	summation of moments	yes	1.07	1	88	1
7	find max M location, cantilever	yes	1.07	1	48	1

Table C1-continued. Question categories sorted by performance index.

3	stress-strain curve, proportional limit		1.06	4	275	3
2	thermal strain		1.06	4	1132	9
6	summation of torques & stress		1.06	4	621	6
12	inclined plane, normal and shear stress		1.06	1	613	4
10	integration, find deflection at spot		1.06	1	85	1
3	Poisson's ratio		1.05	3	1281	7
4	factor of safety, definition		1.05	1	217	2
7	find V at particular location, simply supported	yes	1.05	2	357	4
14	sphere, stress		1.05	4	2719	11
4	factor of safety, stresses		1.03	2	1315	9
6	stress		1.03	2	270	3
5	deformation & statics		1.02	2	1446	10
12	principals and max shear from transformation equations, principal stresses		1.01	9	3711	11
8	normal stress, symmetric beam		1.01	7	1800	5
6	deformation		1.01	3	576	5
9	shear flow, built-up beam		1.01	8	3677	14
3	stress-strain curve, yield strength		1.00	4	347	3
3	stress-strain curve, fracture strength		1.00	4	275	3
15	cross section with N, V and M		1.00	7	1257	7
1	bearing stress, flat surfaces		1.00	1	443	5
10	integration, find elastic curve		0.99	5	1071	3
2	normal strain, rotating bar		0.99	1	821	6
8	composite beam, symmetric, moment of inertia		0.99	1	268	3
13	find strain along diagonal		0.99	5	1518	9
8	normal stress, V&M, cantilever beam		0.98	2	1080	4
4	factor of safety, stress & choose best answer		0.98	1	217	2
1	summation of forces, two directions	yes	0.98	2	311	3
10	superposition, cantilever, deflection at spot		0.97	9	2243	10
4	summation of forces and moments	yes	0.97	1	88	1
8	composite beam, non-symmetric, centroid		0.97	2	935	5
13	Hooke's law, change in thickness		0.96	1	83	1
11	value forced to zero, simply supported with deflection forced to zero		0.96	1	82	1

Table C1-continued. Question categories sorted by performance index.

7	max M, cantilever	yes	0.96	1	48	1
7	max M location, simply supported	yes	0.95	1	87	1
11	propped cantilever		0.95	7	1446	7
2	normal strain, co-axial with gap		0.95	1	278	2
3	stress-strain curve, ultimate strength		0.95	4	347	3
4	factor of safety, statics & stress		0.94	3	669	7
11	movable support, cantilever		0.94	1	82	1
1	shear stress, summation of moments, key		0.94	1	224	2
14	cylinder, stress		0.93	8	1598	8
1	normal stress, summation of forces, two directions		0.93	2	415	3
15	simply supported beam		0.93	1	155	1
3	Hooke's law, Poisson's ratio		0.93	1	260	2
6	stress & deformation, choose best answer		0.92	3	1631	10
7	ground reactions, simply supported, one side	yes	0.91	1	87	1
10	integration, boundary conditions, V(x) or M(x)		0.91	5	1445	3
12	read Mohr's circle, principals		0.90	3	335	4
15	cylindrical post		0.90	9	1371	8
2	shear strain		0.89	5	1356	8
9	rectangular, V&M, cantilever, shear stress		0.87	4	2748	5
6	summation of torques & deformation		0.87	1	769	4
13	find strains from strain gages		0.85	6	1849	5
3	stress-strain curve, Young's modulus		0.85	4	347	3
9	circular, V&M, simply-supported, shear stress, cylinders		0.85	2	704	4
14	sphere, strain		0.84	3	1445	10
5	free thermal expansion		0.83	1	88	1
7	find M at particular location, simply supported	yes	0.83	1	222	2
10	superposition, overhang, deflection at spot		0.83	4	1510	8
10	superposition, simply supported, deflection at spot		0.82	6	1348	9
6	power & deformation		0.82	1	1107	6
6	indeterminate, concentric		0.81	3	1535	10
15	rectangular post		0.80	12	3403	15
14	cylinder, strain		0.78	3	1222	9

Table C1-continued. Question categories sorted by performance index.

13	principal orientation		0.78	1	399	3
10	integration, boundary conditions, w(x)		0.78	2	350	1
1	direct shear stress, punch		0.77	1	278	2
9	flanged, shear stress, I-beam		0.76	8	1731	9
14	cylinder, change in dimension		0.76	1	83	1
10	integration, boundary conditions, θ(x)		0.76	5	1210	2
10	superposition, doubly overhung, deflection at spot		0.75	2	426	2
5	indeterminate, end-to-end		0.75	1	298	3
9	rectangular, V&M, simply-supported, shear stress		0.75	1	313	4
9	circular, V&M, cantilever, shear stress, pipes		0.75	1	268	3
5	indeterminate, coaxial		0.74	2	407	3
6	indeterminate, end-to-end		0.72	4	1117	9
2	normal strain, rotating bar with gap		0.71	2	311	3
11	three supports		0.71	3	1300	10
3	shear modulus		0.71	2	415	3
6	summation of torques & power & deformation		0.70	2	853	7
14	cylinder, welded cylinder		0.68	5	1435	8
3	stress-strain curve, true fracture strength		0.66	4	224	2
5	indeterminate, rotating bar		0.63	1	88	1
11	movable support, simply supported		0.63	5	1192	6
8	combined loading, rectangular cross section		0.61	6	1338	7
5	indeterminate, rotating bar with gap		0.54	1	190	1
15	pressurized pipe		0.51	5	1048	7
5	indeterminate thermal, end-to-end (two materials)		0.51	2	639	4
5	indeterminate thermal, coaxial		0.47	1	617	5

Table C1-continued. Question categories sorted by performance index.