Engineering Analytic Principles and Predictive Computational Skills for K-12 Students:

Statistics on High School Age-Possible Engineering Materials Topics to Engineering and Technology Educators and Curriculum Developers

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Introduction

In the most recent decade, middle and high schools across the United States have tried to incorporate engineering design into traditional technology curriculum, with various degrees of success; however, “the fragmented focus and lack of a clear curriculum framework” had been “detrimental to the potential of the field and have hindered efforts aimed at achieving the stated goals of technological literacy for all students” (Smith and Wicklein, 2007, pp. 2-3). A report issued on September 8, 2009, by the Committee on K-12 Engineering Education established by the National Academy of Engineering and the National Research Council, titled *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* (2009), confirmed the existence of similar problems, such as the “absence of a clear description of which engineering knowledge, skills, and habits of mind are most important, how they relate to and build on one another, and how and when (i.e., at what age) they should be introduced to students” (pp. 7-8; p. 151). K-12 engineering curriculum in the United States remains skeletal so far; its main focus is on generic design process using a “trial-and-error” approach; and the coverage of analytic and predictive knowledge contents is generally in an “ad hoc” fashion and not sequentially structured. In response to the above problems, many scholars have voiced their points of view. Hacker (2011) pointed out that “trial-and-error problem solving takes substantial classroom time, and often does not allow teachers and students to focus on the most important learning goals.” Lewis (2007, pp. 846-848) discussed the need to: (a). establish a “codified body of knowledge that can be ordered and articulated across the grades” instead of short term efforts focused on a particular topic or unit, and (b). make engineering education a coherent system with the creation of content standards for the subject area, in line with science and technology education.

High School Age-possible Engineering Topics (Engineering Materials)

Research Questions and Practical Conceptual Framework

The above evaluation of the current status of K-12 engineering education in the United States could lead to these questions: (1). “How could we determine what engineering analytic principles and predictive skills from what subject should be taught to students at what Grade in the K-12 curriculum, in a rational and scientific way?” (2). “How could we make sure that what students learned from high school engineering curriculum could be transferred to university programs?” Based on the way engineering curriculum has been historically developed, I have constructed a practical conceptual framework to answer the above two questions. If we read any typical information sheet for university level undergraduate engineering program, we will see that the courses are organized in a sequence based on the fulfillment of pre-requisites in mathematics, physics, chemistry, technology and previous engineering courses; and these pre-requisites are usually listed in course descriptions. Therefore, we could hypothesize that the same principles used historically in the development of curricular structure in university undergraduate engineering programs could apply to the selection of K-12 age-possible engineering analytic principles and predictive skills for any particular Grade, and for any particular subject of engineering. In addition, based on the fact that university undergraduate engineering textbooks, especially those used in foundation courses (such as statics, dynamics, strength of materials, engineering economics, etc.), all contain portions that are based on pre-calculus mathematics and scientific principles which are usually covered in K-12 mathematics and science courses, we could also hypothesize that these pre-calculus portions of engineering topics could possibly be taught at various Grade levels, provided that the pre-requisite pre-calculus mathematics and science principles have been covered in previous Grade levels (or in some cases, taught as special topics); and the coverage of such pre-requisites are usually mandated by the performance standards in mathematics and science established by any particular state. This conceptual framework has been used as a practical tool for the initial determination of 9th grade age-possible statics and fluid mechanics topics. The step-by-step procedure or the "ideal" procedure (Locke, 2009a, pp. 26-27) includes the following (*Figure 1*): (1) selection of data source (selection of popular university undergraduate engineering textbooks and other instructional and learning materials); (2) analysis of data source (careful reading of every paragraph in the body text as well as relevant computational formulas to find and record the pre-requisite mathematics skills and scientific principles needed for each topic; (3) comparison (between the recorded mathematics and science pre-requisites, and my interpretation of the mandates of the Performance Standards for Mathematics and Sciences of the Department of Education of a selected state, in this case, the State of Georgia, to determine the Grade level for the age-possible inclusion of the topics). I selected the State of Georgia's Standards as a reference for the research because (1) the University of Georgia, my alma mater, gave me the opportunity to study the subject of K-12 engineering education and (2) many professors at the College of Education and the College of Agricultural and Environmental Sciences (Department of Biological and Agricultural Engineering) offered me valuable advice and criticism. Due to the fact that the variations among the K-12 mathematics and science performance standards of the 50 states are not substantial, the outcomes of the research should apply to other states with some reasonable adaptations.

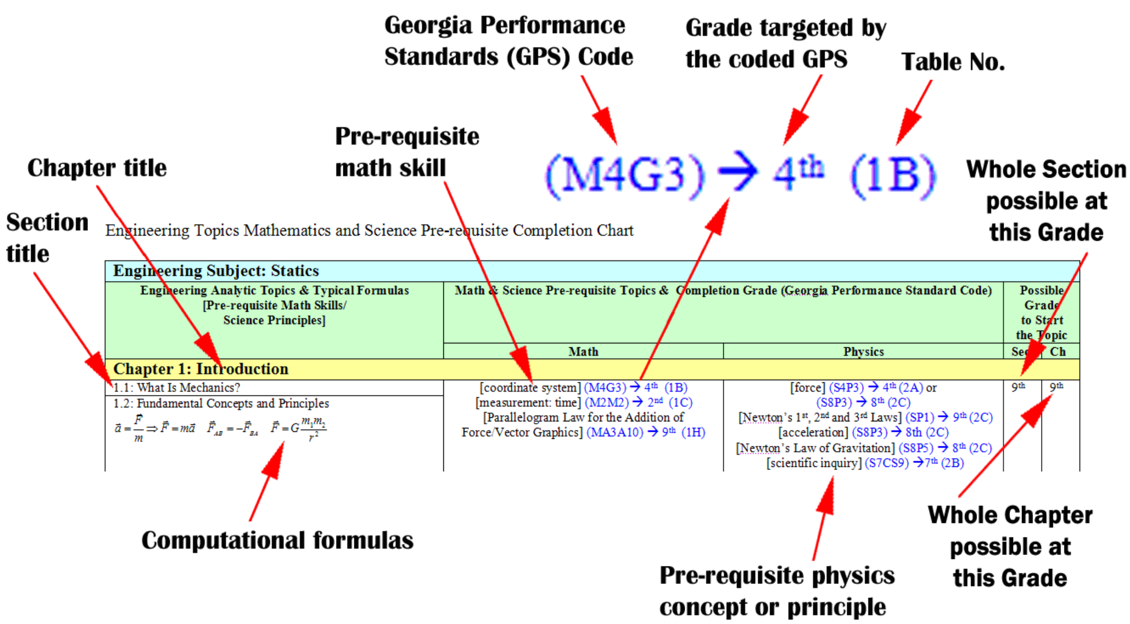

Figure 1. The original research data table used to initially determine high school 9th Grade age-possible statics topics.

After completing all lower-division undergraduate mechanical engineering courses plus two upper-division ones, and conducting a careful and fairly thorough examination of many other college-level engineering textbooks, I have made the conclusion that all engineering textbooks include the following major elements:

(1) **<u>Descriptive and informational:</u>** Paragraphs, data tables, charts, graphs, illustrations and photos that explain natural phenomena, scientific principles, properties of materials, behaviors of structures and systems, in "plain English," without going into the details of analytic and predictive computations using formulas based on mathematics skills.

(2) **<u>Analytic and predictive:</u>** Mathematics-based formulas, including those used in pre-requisite physics and chemistry concepts, principles and analysis, and those used in engineering analysis and design, and step-by-step procedures, including sample problems with solutions, for analyzing problems, predicting outcomes, or designing systems or products; and these mathematics skills could be at either pre-calculus level, i.e., arithmetic, trigonometry, geometry, algebra, or at calculus level, i.e., integration and differentiation.

In terms of the relative amount of each of the above major elements in the overall composition of the content of the textbooks, all sets of college-level engineering textbooks used in any particular course or subject could be classified into three major categories; i.e., (1) Mixture of Pre-calculus and Calculus, (2) Heavily Pre-calculus, and (3) Heavily Descriptive and Informational. It takes different amounts of time and efforts to examine different sets of textbooks under different categories in order to tentatively determine and select K12 age-possible engineering content knowledge and skills, including descriptive and informational materials, analytic and predictive computational formulas and step-by-step problem solving procedures; and the procedure of this examination include (a) interpretation of the mandates of the Performance Standards for Mathematics and Sciences of the Department of Education of a selected state, in this case, the State of Georgia, to create a coded list of items of mathematics, physics and chemistry concepts and skills, such as *M4G3→4th Grade (1B)* shown in *Figure 1*, from the original online government document, to be used for comparison with the mathematics, physics and chemistry concepts and skills found from the relevant textbooks; (b) paragraph-by-paragraph or page-by-page examination of the selected textbooks for the extraction and documentation of the mathematics, physics and chemistry concepts and skills needed to understand the content and to solve homework problems; and (c) comparison between the interpreted, itemized and coded lists of Performance Standards and the items extracted from the textbooks, to tentatively determine and select sections and chapters in the textbooks that could be K12 age-possible. In the United States, we have a very decentralized management structure for the publication and adaptation of textbooks; and this is especially true for textbooks used in the institutions of higher education where professors usually select textbooks out of their own choices free from government intervention; for any college courses or subject, we can find several excellent and popular textbooks, all of them cover a majority of similar topics plus a small number of different ones; therefore, to be holistic and comprehensive, at least two of the most popular textbooks will be used, one as the "primary source of data" and the rest as "secondary source of data" and "additional sources of data." The nature of composition of the above-mentioned three major categories of textbooks and the average amount of time it takes for their examination are as follows:

1. **Mixture of Pre-calculus and Calculus:** Textbooks under this category include, for the undergraduate mechanical engineering major, those used in the courses of statics, dynamics, strength of materials, electric machines, mechanical design, aerodynamics, fluid mechanics, electrical circuits, heat transfer, thermodynamics, and others. For these textbooks, calculus and pre-calculus skills are used intermittently throughout substantial portions of most of the chapters. These textbooks are usually voluminous and the numbers of pages range from 600 to 900. Therefore, a thorough investigation of all paragraphs, formulas, and even sample problems in the textbooks, and a very detailed record of all pertinent information in tabular forms is needed to determine and to select K-12 age-possible engineering topics for different grade levels. My research projects on the subjects of statics and fluid mechanics have been completed this way. This procedure is very thorough and time-consuming and for one subject, it takes between 3 to 5 weeks for one textbook (the "primary source of data"), and additional 1 to 2 weeks for another textbook (the "secondary source of data" used to pick up additional K12 age-possible topics); these amounts of time cover careful reading of all chapters, sections, and even appendices and glossaries throughout the entire textbooks, analysis and recording of mathematics, physics and chemistry concepts and skills involved, typing of titles of chapters, sections, formulas, names of pre-requisite items, write-ups of conclusions, as well as a section-by-section review. Typing of titles of chapters, sections, and formulas could take up to one third of the above amounts of time needed for the research. It is the exact or "ideal" procedure advocated in my published Vision Paper.

2. **Heavily Pre-calculus:** Textbooks under this category include those used in the courses of engineering economics, probability and statistics, and others. For these textbooks, the mathematics skills involved in the majority or even the overwhelming majority of chapters and sections are at pre-calculus level; the calculus skills involved in a few sections or chapters are the very beginning ones such as [first integral] and [first derivative]; and the principles and skills related to physics and chemistry are also the very basic ones; therefore, a less time-consuming approach is used to determine and select K12 age-possible engineering topics, by carefully examine each page in the textbooks to record (1) the pre-calculus level mathematics skills as well as physics and chemistry concepts, principles and skills found in all pages; (2) the calculus-level mathematics skills found in some pages, the page numbers where these calculus skills are found, the numbers and names as well as the pages ranges of the sections involving the calculus skills; and (3) result of comparison between the pre-calculus skills as well as physics and chemistry concepts and skills found throughout the textbooks, and the mandates of the Performance Standards for Mathematics and Sciences of the Department of Education of a selected state, in this case, the State of Georgia, to determine the earliest Grade level for the age-possible inclusion of the topics. My research projects on the subjects of engineering economics, probability and statistics, and engineering materials have been completed this way. This procedure is fairly thorough but much less time-consuming because no record of mathematics-based formulas or typing of the names of chapters and sections of the textbooks that involve only pre-calculus mathematics skills is needed, and for one subject, it takes between 5 to 7 days for one textbook (the "primary source of data") and additional 2 to 4 days for another textbook (the "secondary source of data"). These amounts of time cover careful reading of all chapters, sections, and even appendices and glossaries throughout the entire textbooks, analysis and recording of

mathematics, physics and chemistry concepts and skills involved as pre-requisites, typing of page numbers and titles of chapters and sections involving calculus stills as well as numbers of the individual pages involved, write-ups of conclusions, as well as a section-by-section review. It is a convenient and "ad hoc" revision of the "ideal" procedure advocated in my published Vision Paper.

3. **Heavily Descriptive and Informational:** Textbooks under this category include those used in the courses of introduction to science, engineering and technology, ethics and professionalism in engineering, and others. These textbooks involve little or no mathematics skills; their primary goal is to expose students to broad knowledge about engineering, science, technology, as well as their relationship with "other stuff" such as society, ecology, legal system, philosophy, and others. Similar method as the one used for the "Heavily Pre-calculus" textbooks is used here but the amounts of time spent is substantially reduced because, for the "Heavily Descriptive and Informational" textbook, mathematics, physics and chemistry pre-requisites are rarely involved. For one subject, it takes between 1 to 3 days for one textbook (the "primary source of data") and additional 1 to 2 days for another textbook (the "secondary source of data"). These amounts of time cover careful reading of all chapters, sections, and even appendices and glossaries throughout the entire textbooks, analysis and recording of a few mathematics, physics and chemistry concepts and skills involved as pre-requisites, write-ups of conclusions, as well as a section-by-section review. It is a convenient, "ad hoc" and more drastic revision of the "ideal" procedure advocated in my published Vision Paper.

For the particular subject of Engineering Materials, the knowledge content covered in the reading of the Textbooks 1 through 5 selected in this research, classroom lecture, homework assignments and quizzes or examinations are mostly using predictive and computational formulas based on pre-calculus mathematics concepts and skills, with only a few sections in Textbooks 3, 4 and 5 involving a few beginning calculus skills such as [first integral], [first derivative], [first partial derivative], and [gradient], and the involvement of concepts and skills in physics and chemistry is minimal and in most cases, these concepts and skills are explained in the selected Textbooks in sufficient details such that prior completion of physics and chemistry courses are helpful but concurrent enrollment in these courses or even a short training session on relevant topics could be sufficient. Therefore, for all practical purposes, all pages of the selected Textbooks 1 through 5 used as reference sources have been carefully and thoroughly examined to record the pre-calculus-level mathematics skills, physics and chemistry concepts and skills, as well as calculus level ones with the numbers and names of relevant chapters or sections. An overall analysis of the data so collected has then been conducted to reach a practical conclusion about the selection of K12 age-possible topics from the selected Textbooks 1 through 5.

Sources of Data

Table 1 lists the college-level textbooks used for the extraction of analytic and predictive principles and computational formulas, as well as physics and chemistry concepts and skills related to the subject of engineering materials.

Table 1. Data Source (Engineering Materials Textbooks)

	Textbooks Examined				
	Textbook 1	**Textbook 2**	**Textbook 3**	**Textbook 4**	**Textbook 5**
Title	Engineering Materials Properties and Selection, 8th Edition	Introduction to Materials and Processes	Material Science and Engineering An Introduction	The Science and Engineering of Materials, 6th Edition	Manufacturing Processes for Engineering Materials, 4th Edition
Authors	Kenneth G. Budinski and Michael K. Budinski	John R. Wright and Larry D. Helsel	William D. Callister, Jr., and David G. Rethwisch	Donald R. Askland, Pradeep P. Fulay, Wendelin J. Wright	Serope Kalpakjian and Steven R. Schmid
Publisher	Prentice Hall (Pearson)	Delmar Publishers	John Wiley & Sons Inc	Cengage Learning	Prentice Hall Pearson Education
Year	2005	1996	2010	2010	2003
ISBN	0-13-183779-6	0-8273-5020-1	978-0-470-41997-7	13: 978-0-495-29602-7	0-13-040871-9
Number of Pages	834	486	944	900	927

Initial Determination of High School Age-Possible Engineering Materials Topics

The outcome of this research is very encouraging. Tables 2A through 2E indicate that: (1). **for Textbook 1**, 100% of all sections, and 100 % of the volume in the selected textbook is based on pre-calculus mathematics; (2). **for Textbook 2**, 100% of all sections, and 100 % of the volume in the selected textbook is based on pre-calculus mathematics; (3) **for Textbook 3**, 97.1% of all sections (or 84.9% of content), and 98.7% of the volume is based on pre-calculus mathematics; (4) **for Textbook 4**, 97.5% of all sections (or 90.1% of content), and 99.2 % of the volume is based on pre-calculus mathematics and on principles of physics; (5) **for Textbook 5**, 93.3% of all sections (or 78.0% of content), and 97.6 % of the volume is based on pre-calculus mathematics; and (6) as shown on Tables 2A through 2E, the principles and skills related to the subjects of physics and chemistry are very basic; most of them are explained in sufficient details in the body text or in the glossary sections such that prior courses in physics and chemistry are helpful but not absolutely necessary; alternatively, relevant principles and skills could be taught or reviewed in special training sessions at the start of the course.

Table 2A. Statistic on Textbook 1 (Engineering Materials Properties and Selection, 8th Edition, by Kenneth G. Budinski and Michael K. Budinski)

Pre-Calculus Level Concepts and Skills Found in All Chapters/Sections			**Page Information**	
Mathematics	**Physics**	**Chemistry**	**Page Numbers**	**Number of Pages**
[four operations], [percentage], [root], [power], [inequality], [graph], [measurement] (length, width, depth, radius, angle), [graph], [area], and [volume]	[mass], [velocity], [force], [pressure], [pressure], [impact], [energy], [stress], [strain], [friction]	[periodic table], [atomic structure], [chemical symbols], [chemical equation], and [temperature]	N/A	N/A
Calculus Level Mathematics			N/A	N/A
Concepts and Skills	**Chapters/Sections**			
N/A	N/A		0	0
Chapters with Pre-Calculus Level Mathematics Concepts and Skills ONLY Volume = Total Number of Pages – Number of Pages with Calculus Skills = 834 - 0 = 834 Number of Chapters = Total Number of Chapters – Number of Chapters with Calculus Skills = 21 – 0 = 21				

Statistical Summary

Total Number of Pages Covered by Text (Excluding "Index"): 834	Total Numbers of Chapters: 21
Percentage of Pre-Calculus Sections $\%_{\text{Pre-Calculus}} = \left(\frac{\text{Number of Pre-Calculus Chapters}}{\text{Total Number of Chapters}}\right)(100\%)$ $= \left(\frac{21}{21}\right)(100\%) = 100.0\%$	**Percentage of Chapters with Calculus Sections** $\%_{\text{Calculus}} = \left(\frac{\text{Number of Chapters with Calculus Sections}}{\text{Total Number of Chapters}}\right)(100\%)$ $= \left(\frac{0}{21}\right)(100\%) = 0\%$
Total Numbers of Chapters with Pre-Calculus Skills Only: 21 out of 21	**Total Number of Pages with Pre-Calculus Skills Only:** 834 out of 834

Percentage of Pre-Calculus Volume:

$$\%_{\text{Pre-Calculus}} = \left(\frac{\text{Number of Pre-Calculus Pages}}{\text{Total Number of Pages}}\right)(100\%) = \left(\frac{834}{834}\right)(100\%) = 100.0\%$$

Conclusion on the Textbook:

(1) Knowledge content is basically descriptive and informational. It is suitable for a material selection course in a college technology or engineering technology program, but probably not for a science and engineering of materials course in an engineering program due to lack of vigorous inclusion of formula-based predictive and computational skills.
(2) Before a high school level science and engineering of materials textbook with all age-possible topics involving predictive computational formulas is developed, this book could be handy for teaching high school students the basic knowledge about different types of materials and their usage.
(3) This book offers a great wealth of information and numerical data, international standards, and a listing of relevant websites (pages 817-821).
(4) All content in this textbook is age-possible for high school students.

Table 2B. Statistic on Textbook 2 (Introduction to Materials and Processes by John R. Wright and Larry D. Helsel)

Pre-Calculus Level Concepts and Skills Found in All Chapters/Sections			Page Information	
Mathematics	**Physics**	**Chemistry**	**Page Numbers**	**Number of Pages**
[four operations], [square root], [table], [charts], [flow chart], [graph], [percentage], [measurement] (diameter, radius, angle, length, height, depth), [unit], [fraction], [pi]	[force], [stress], [strain], [speed], [time], [motion]	[chemical symbols], and [periodic tables]	N/A	N/A
Calculus Level Mathematics				
Concepts and Skills	**Chapters/Sections**			
N/A	N/A		N/A	0

Chapters with Pre-Calculus Level Mathematics Concepts and Skills ONLY
Volume = Total Number of Pages – Number of Pages with Calculus Skills = 486 - 0 = 486
Number of Chapters = Total Number of Chapters – Number of Chapters with Calculus Skills = 24 – 0 = 24

Statistical Summary

Total Number of Pages Covered by Text (Excluding "Index"): 486	Total Numbers of Chapters: 24
Percentage of Pre-Calculus Chapters $\%_{\text{Pre-Calculus}} = \left(\frac{\text{Number of Pre-Calculus Chapters}}{\text{Total Number of Chapters}}\right)(100\%)$ $= \left(\frac{24}{24}\right)(100\%) = 100.0\%$	**Percentage of Chapters with Calculus Sections** $\%_{\text{Calculus}} = \left(\frac{\text{Number of Chapters with Calculus Sections}}{\text{Total Number of Chapters}}\right)(100\%)$ $= \left(\frac{0}{24}\right)(100\%) = 0\%$
Total Numbers of Chapters with Pre-Calculus Skills Only: 24 out of 24	**Total Number of Pages with Pre-Calculus Skills Only:** 486 out of 486

Percentage of Pre-Calculus Volume:

$$\%_{\text{Pre-Calculus}} = \left(\frac{\text{Number of Pre-Calculus Pages}}{\text{Total Number of Pages}}\right)(100\%) = \left(\frac{486}{486}\right)(100\%) = 100\%$$

Conclusion on the Textbook:

(1) This book is a handy textbook immediately possible for an introductory high school engineering materials course.
(2) The mathematics, physics, and chemistry concepts and skills needed for reading this book are minimal and rarely beyond a basic understanding of the concepts; a few pages contain predictive and computational formulas.
(3) Approximately 80% of content in this book is descriptive and informational.
(4) The end of each chapter is followed by Review Questions and Suggested Activities.
(5) This book is intended for students of engineering and technology in an introductory materials and processes course, and is easy to

read. It could be used at high school level.

Table 2C. Statistic on Textbook 3 (Material Science and Engineering An Introduction, by William D. Callister, Jr., and David G. Rethwisch)

Pre-Calculus Level Concepts and Skills Found in All Chapters/Sections			**Page Information**			
Mathematics	**Physics**	**Chemistry**	**Pages with Calculus Skills**		**Sections with Calculus Skills**	
			Page Numbers	**Number of Pages**	**Page Numbers**	**Number of Pages**
[four operations], [fraction], [inequality], [percentage], [percentage], [system of units], [table], [chart], [graph], [schematics], [power] or [exponent], [root], [plane], [point], [axis], [coordinates], [trigonometric functions], [scientific notation], [geometric shapes and solids] (square, rectangle, circle, sphere, cylinder), [log], [natural log], [summation]	[chemical symbol], [atomic structure], [periodic table], [material state] (gas, liquid, solid), [solution], [molecular structure], [electron structure], [conductivity], [chemical equation], [phase] and [equilibrium].	[energy], [force], [impact], [stress], [strain], [temperature], [Ohm's Law], [dielectric], [conductivity], [thermal conductivity], [insulation], [electromagnetic spectrum], [refraction], [reflection], [absorption], [transmission], [specific heat]	N/A	N/A	N/A	N/A

Calculus Level Mathematics					
Concepts and Skills	**Chapters/Sections**				
[first integral], [first derivative], [gradient], [first partial derivative]	2.5 Bonding Forces and Energies	29	1	28-30	3
	5.3 Steady State Diffusion	126, 127	2	126-127	2
	5.4 Nonsteady-State Diffusion	128, 129	2	128-132	5
	6.3 Stress-Strain Behavior	157	1	156-159	4
	6.6 Tensile Properties	168	1	162-170	9
	8.13 Stress and Temperature Effects	267, 268	2	266-268	3
	10.3 The Kinetics of Phase Transformations	353	1	344-355	12
	19.2 Heat Capacity	782	1	782-785	4
	19.4 Thermal Conductivity	789	1	789-792	4
Total Number of Pages			12		46

Chapters with Pre-Calculus Level Mathematics Concepts and Skills ONLY

Volume (Pages with Pre-Calculus Skills) = Total Number of Pages - Number of Pages with Calculus Skills = 944 - 12 = 932

Volume (Pages Excluding Sections with Calculus Skills) =

Total Number of Pages – Number of Pages of Sections with Calculus Skills = 944 - 46 = 898

Number of Chapters = Total Number of Chapters - Number of Chapters with Calculus Skills = 22 - 6 = 16

Number of Sections = Total Number of Sections - Number of Sections with Calculus Skills = 278 - 8 = 270

Statistical Summary

Total Number of Pages Covered by Text (Excluding "Index"): 944

Total Numbers of Chapters and Sections: 22, 278

Percentage of Pre-Calculus Chapters

$$\%_{\substack{\text{Pre-Calculus}\\ \text{Chapters}}} = \left(\frac{\text{Number of Pre-Calculus Chapters}}{\text{Total Number of Chapters}}\right)(100\%)$$

$$= \left(\frac{16}{22}\right)(100\%) = 72.7\%$$

Percentage of Pre-Calculus Sections

$$\%_{\substack{\text{Pre-Calculu}\\ \text{Sections}}} = \left(\frac{\text{Number of Pre-Calculus Sectionss}}{\text{Total Number of Sectionss}}\right)(100\%)$$

$$= \left(\frac{270}{278}\right)(100\%) = 97.1\%$$

Average Percentage of Pre-Calculus Content

$$\%_{\substack{\text{Pre-Calculu}\\ \text{Content}}} = \frac{\%_{\substack{\text{Pre-Calculus}\\ \text{Chapters}}} + \%_{\substack{\text{Pre-Calculus}\\ \text{Sections}}}}{2} = \frac{72.7\% + 97.1\%}{2} = 84.9\%$$

Percentage of Chapters with Calculus Sections

$$\%_{\substack{\text{Calculus}\\ \text{Chapters}}} = \left(\frac{\text{Number of Chapters with Calculus Sections}}{\text{Total Number of Chapters}}\right)(100\%)$$

$$= \left(\frac{6}{22}\right)(100\%) = 27.3\%$$

Percentage of Sections with Calculus Skills

$$\%_{\substack{\text{Calculus}\\ \text{Sections}}} = \left(\frac{\text{Number of Sectionss with Calculus Skills}}{\text{Total Number of Sections}}\right)(100\%)$$

$$= \left(\frac{8}{278}\right)(100\%) = 2.9\%$$

Average Percentage of Calculus Content

$$\%_{\substack{\text{Calculus}\\ \text{Content}}} = \frac{\%_{\substack{\text{Calculus}\\ \text{Chapters}}} + \%_{\substack{\text{Pre-Calculus}\\ \text{Sections}}}}{2} = \frac{27.3\% + 2.9\%}{2} = 15.1\%$$

Total Numbers of Chapters with Pre-Calculus Skills Only: 16 out of 22

Total Number of Pages with Pre-Calculus Skills Only: 932 out of 944

Percentage of Pre-Calculus Volume:
$\%_{\text{Pre-Calculus}} = \left(\frac{\text{Number of Pre-Calculus Pages}}{\text{Total Number of Pages}}\right)(100\%) = \left(\frac{932}{944}\right)(100\%) = 98.7\%$

Conclusion on the Textbook:

(1) The mathematics concepts and skills needed for reading and homework assignments using formulas are mostly at pre-calculus level. For some sections, beginning calculus-based mathematics skills appear in the analytic and predictive formulas.
(2) Basic concepts and information related to chemistry are needed; but they are covered in enough details in the textbook.
(3) Basic understanding of physics concepts is needed; however, the book covers these topics in sufficient details such that a prior completion of a physics course is not absolutely necessary.
(4) Approximately 60% of the topics in this textbook are descriptive and informational, without any predictive computational formulas. Therefore, this textbook is age-possible for high school students. Treating the calculus skills as special mathematics topics, this textbook could be age-possible for high school students.

Table 2D. Statistic on Textbook 4 (The Science and Engineering of Materials, 6th Edition, by Donald R. Askland, Pradeep P. Fulay, Wendelin J. Wright)

Pre-Calculus Level Concepts and Skills Found in All Chapters/Sections			Page Information			
Mathematics	**Physics**	**Chemistry**	**Pages with Calculus Skills**		**Sections with Calculus Skills**	
			Page Numbers	**Number of Pages**	**Page Numbers**	**Number of Pages**
[four operations], [integer], [fraction], [scientific notation], [inequality], [percentage], [geometric shapes and solids] (circle, square, sphere, cube, etc.), [geometric measurements] (length, height, width, radius, etc), [coordinates and axes], [power], [root], [infinity], [trigonometric functions], [exponent], [summation], [log], [natural log], [chart], and [graph]	[energy], [force], [impact], [stress], [strain], [temperature], [Ohm's Law], [dielectric], [conductivity], [thermal conductivity], [insulation], [electromagnetic spectrum], [refraction], [reflection], [absorption], [transmission], and [specific heat]	[atomic structure], [atomic bonding], [periodic table], [chemical symbol], [chemical equation], [electronic structure]	N/A	N/A	N/A	N/A
Calculus Level Mathematics						
Concepts and Skills	**Chapters/Sections**					
[first partial derivative], [first derivative], [first integral]	Section 5-8 Composition Profile [Fick's Second Law]		177, 178	2	177-182	6
	Section 6-2 Terminology for Mechanical Properties		202	1	199-204	6
	Section 6-5 True Stress and True Strain		216	1	216-218	3
	Section 7-8 Application of Fatigue Testing		272-273	2	270-274	5
	Section 8-1 Relationship of Cold Working to the Stress-Strain Curve		295	1	292-297	6
Total Number of Pages				8		26

Chapters with Pre-Calculus Level Mathematics Concepts and Skills ONLY
Volume (Pages with Pre-Calculus Skills) = Total Number of Pages – Number of Pages with Calculus Skills = 900 - 7 = 893
Volume (Pages Excluding Sections with Pre-Calculus Skills) =
Total Number of Pages – Number of Pages of Sections with Calculus Skills = 900 - 26 = 874
Number of Chapters = Total Number of Chapters – Number of Chapters with Calculus Skills = 23 – 4 = 19
Number of Sections = Total Number of Sections – Number of Sections with Calculus Skills = 204 – 5 = 199

Statistical Summary

Total Number of Pages Covered by Text (Excluding "Index"): 900	**Total Numbers of Chapters and Sections:** 23, 204
Percentage of Pre-Calculus Chapters $\%_{\substack{\text{Pre-Calculus}\\\text{Chapters}}} = \left(\frac{\text{Number of Pre-Calculus Chapters}}{\text{Total Number of Chapters}}\right)(100\%)$ $= \left(\frac{19}{23}\right)(100\%) = 82.6\%$	**Percentage of Chapters with Calculus Sections** $\%_{\substack{\text{Calculus}\\\text{Chapters}}} = \left(\frac{\text{Number of Chapters with Calculus Sections}}{\text{Total Number of Chapters}}\right)(100\%)$ $= \left(\frac{4}{23}\right)(100\%) = 17.4\%$
Percentage of Pre-Calculus Sections	**Percentage of Sections with Calculus Skills**

<table>
<tr><td>$\%_{\substack{\text{Pre-Calculu}\\ \text{Sections}}} = \left(\frac{\text{Number of Pre-Calculus Sectionss}}{\text{Total Number of Sectionss}}\right)(100\%)$
$= \left(\frac{199}{204}\right)(100\%) = 97.5\%$
Average Percentage of Pre-Calculus Content
$\%_{\substack{\text{Pre-Calculu}\\ \text{Content}}} = \frac{\%_{\substack{\text{Pre-Calculus}\\ \text{Chapters}}} + \%_{\substack{\text{Pre-Calculus}\\ \text{Sections}}}}{2} = \frac{82.6\% + 97.5\%}{2} = 90.1\%$</td><td>$\%_{\substack{\text{Calculus}\\ \text{Sections}}} = \left(\frac{\text{Number of Sectionss with Calculus Skills}}{\text{Total Number of Sections}}\right)(100\%)$
$= \left(\frac{5}{204}\right)(100\%) = 2.5\%$
Average Percentage of Calculus Content
$\%_{\substack{\text{Calculus}\\ \text{Content}}} = \frac{\%_{\substack{\text{Calculus}\\ \text{Chapters}}} + \%_{\substack{\text{Pre-Calculus}\\ \text{Sections}}}}{2} = \frac{17.4\% + 2.5\%}{2} = 9.9\%$</td></tr>
<tr><td>Total Numbers of Chapters with Pre-Calculus Skills Only:
19 out of 23</td><td>Total Number of Pages with Pre-Calculus Skills Only:
893 out of 900</td></tr>
<tr><td colspan="2">Percentage of Pre-Calculus Volume:
$\%_{\substack{\text{Pre-Calculus}\\ \text{Volume}}} = \left(\frac{\text{Number of Pre-Calculus Pages}}{\text{Total Number of Pages}}\right)(100\%) = \left(\frac{893}{900}\right)(100\%) = 99.2\%$</td></tr>
</table>

Conclusion on the Textbook:

(1) A few calculus-level mathematics skills could be treated as special topics of mathematics before the start of the relevant chapters if needed.
(2) Basic concepts and information related to chemistry and to physics are covered in enough details in the textbook; thus, a prior chemistry or physics course or its concurrent enrollment might be helpful but is not an absolute pre-requisite.
(3) Approximately 60% of the topics in this textbook are descriptive and informational, without any predictive computational formulas. Therefore, this textbook is age-possible for high school students.

Table 2E. Statistic on Textbook 5 (Manufacturing Processes for Engineering Materials, 4th Edition, by Serope Kalpakjian and Steven R. Schmid)

<table>
<tr><th colspan="3">Pre-Calculus Level Concepts and Skills Found in All Chapters/Sections</th><th colspan="4">Page Information</th></tr>
<tr><th rowspan="2">Mathematics</th><th rowspan="2">Physics</th><th rowspan="2">Chemistry</th><th colspan="2">Pages with Calculus Skills</th><th colspan="2">Sections with Calculus Skills</th></tr>
<tr><th>Page Numbers</th><th>Number of Pages</th><th>Page Numbers</th><th>Number of Pages</th></tr>
<tr><td>[four operations], [percentage], [fraction], [integer], [power], [root], [inequality], [log], [natural log], [table], [chart], [flow chart], [graph], [measurement] (length, width, depth, radius, angle), [area] (circle, rectangle, triangle, etc.), [volume] (cylinder, prism, sphere, etc.), [trigonometric functions], [geometric shapes and solids] (circle, rectangle, triangle, sphere, prism), and [summation]</td><td>[force], [mass], [speed], [time], [stress]. [strain], [dielectric], [friction]</td><td>[specific heat], [conduction] (electrical and thermal)</td><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="3">Calculus Level Mathematics</th><td colspan="4" rowspan="2"></td></tr>
<tr><th>Concepts and Skills</th><th colspan="2">Chapters/Sections/Subsections</th></tr>
<tr><td rowspan="17">[first integral] and [first derivative]</td><td colspan="2">2.2.2 True stress and true strain</td><td>31</td><td>1</td><td rowspan="4">27-42</td><td rowspan="4">16</td></tr>
<tr><td colspan="2">2.2.3 True-stress-true-strain curve</td><td>34</td><td>1</td></tr>
<tr><td colspan="2">2.2.4 Instability in simple tension</td><td>36</td><td>1</td></tr>
<tr><td colspan="2">2.2.7 Effects of strain rate</td><td>38, 40</td><td>2</td></tr>
<tr><td colspan="2">2.3 Compression</td><td>43</td><td>1</td><td>43-45</td><td>3</td></tr>
<tr><td colspan="2">2.4 Torsion</td><td>47</td><td>1</td><td>46-48</td><td>3</td></tr>
<tr><td colspan="2">2.12 Work of Deformation</td><td>68, 69</td><td>2</td><td>68-72</td><td>5</td></tr>
<tr><td colspan="2">4.3 Surface texture</td><td>131, 132</td><td>2</td><td>130-134</td><td>5</td></tr>
<tr><td colspan="2">6.2.1 Open-die forging</td><td>263</td><td>1</td><td rowspan="2">260-281</td><td rowspan="2">22</td></tr>
<tr><td colspan="2">6.2.2 Methods of analysis</td><td>264</td><td>1</td></tr>
<tr><td colspan="2">6.3.1 Mechanics of flat rolling</td><td>284, 285, 289</td><td>3</td><td>282-300</td><td>19</td></tr>
<tr><td colspan="2">7.2.1 Elongation</td><td>339</td><td>1</td><td>336-341</td><td>6</td></tr>
<tr><td colspan="2">7.5 Stretch Forming</td><td>361</td><td>1</td><td>360-361</td><td>2</td></tr>
<tr><td colspan="2">7.8.1 Conventional spinning</td><td>363</td><td>1</td><td>364-368</td><td>5</td></tr>
<tr><td colspan="2">8.2 Mechanics of Chip Formation</td><td>408</td><td>1</td><td>405-426</td><td>22</td></tr>
<tr><td colspan="2">8.14 Economics of Machining</td><td>492</td><td>1</td><td>490-494</td><td>5</td></tr>
<tr><td colspan="2">10.3 Thermoplastics Behavior and Properties</td><td>571</td><td>1</td><td>568-575</td><td>8</td></tr>
<tr><td colspan="3">Total Number of Pages</td><td></td><td>22</td><td></td><td>121</td></tr>
<tr><td colspan="7">Chapters with Pre-Calculus Level Mathematics Concepts and Skills ONLY
Volume (Pages with Pre-Calculus Skills) = Total Number of Pages – Number of Pages with Calculus Skills = 927 - 22 = 905
Volume (Pages Excluding Sections with Pre-Calculus Skills) =
Total Number of Pages – Number of Pages of Sections with Calculus Skills = 927 - 121 = 806</td></tr>
</table>

Number of Chapters = Total Number of Chapters – Number of Chapters with Calculus Skills = 16 - 6 = 10
Number of Sections = Total Number of Sections – Number of Sections with Calculus Skills = 195 - 13 = 182

Statistical Summary

Total Number of Pages Covered by Text (Excluding "Index"): 927	**Total Numbers of Chapters and Sections:** 16, 195
Percentage of Pre-Calculus Chapters $\%_{\substack{\text{Pre-Calculus}\\\text{Chapters}}} = \left(\frac{\text{Number of Pre-Calculus Chapters}}{\text{Total Number of Chapters}}\right)(100\%) = \left(\frac{10}{16}\right)(100\%) = 62.6\%$	**Percentage of Chapters with Calculus Sections** $\%_{\substack{\text{Calculus}\\\text{Chapters}}} = \left(\frac{\text{Number of Chapters with Calculus Sections}}{\text{Total Number of Chapters}}\right)(100\%) = \left(\frac{6}{16}\right)(100\%) = 37.5\%$
Percentage of Pre-Calculus Sections $\%_{\substack{\text{Pre-Calculu}\\\text{Sections}}} = \left(\frac{\text{Number of Pre-Calculus Sectionss}}{\text{Total Number of Sections}}\right)(100\%) = \left(\frac{182}{195}\right)(100\%) = 93.3\%$	**Percentage of Sections with Calculus Skills** $\%_{\substack{\text{Calculus}\\\text{Sections}}} = \left(\frac{\text{Number of Sectionss with Calculus Skills}}{\text{Total Number of Sections}}\right)(100\%) = \left(\frac{13}{195}\right)(100\%) = 6.7\%$
Average Percentage of Pre-Calculus Content $\%_{\substack{\text{Pre-Calculu}\\\text{Content}}} = \frac{\%_{\substack{\text{Pre-Calculus}\\\text{Chapters}}} + \%_{\substack{\text{Pre-Calculus}\\\text{Sections}}}}{2} = \frac{62.6\% + 93.3\%}{2} = 78.0\%$	**Average Percentage of Calculus Content** $\%_{\substack{\text{Calculus}\\\text{Content}}} = \frac{\%_{\substack{\text{Calculus}\\\text{Chapters}}} + \%_{\substack{\text{Pre-Calculus}\\\text{Sections}}}}{2} = \frac{37.5\% + 6.7\%}{2} = 22.1\%$
Total Numbers of Chapters Pre-Calculus Skills Only: 10 out of 16	**Total Number of Pages with Pre-Calculus Skills Only:** 905 out of 927

Percentage of Pre-Calculus Volume:

$$\%_{\substack{\text{Pre-Calculus}\\\text{Volume}}} = \left(\frac{\text{Number of Pre-Calculus Pages}}{\text{Total Number of Pages}}\right)(100\%) = \left(\frac{905}{927}\right)(100\%) = 97.6\%$$

Conclusion on the Textbook:

(1) This textbook is one of the most popular college engineering textbook intended for university undergraduate mechanical, industrial, metallurgical, and material engineering programs.

(2) For most of the chapters, the mathematics concepts and skills required to read the text and to complete homework assignment are at pre-calculus level. Only about 30 pages in this textbook contain formulas requiring beginning calculus skills; and the total number of pages involved in the related sections or subsections is 22; therefore, if necessary, treating the two beginning calculus skills of as special mathematics topics with a few special training sessions, this textbook could be age-possible for high school students.

(3) Most of the physics and chemistry concepts and skills needed are explained in sufficient details in this textbook.

(4) Approximately 75% of the content in this textbook is descriptive and informational, with little or no inclusion of mathematics-based predictive and computational formulas.

(5) This textbook offers a great wealth of do's and don'ts for appropriate design of product components.

Conclusions and Recommendations

This report has presented (1) information about five popular engineering materials textbooks, including three college-level ones with calculus-based analytic and predictive computational formulas, which have been selected for the initial determination and selection of high school age-possible topics (Table 1), and (2) the outcome of the research on the inclusion of mathematics, physics and chemistry concepts and skills needed for reading and homework assignments (Tables 2A through 2E). The following are recommended: (1) **Pilot study**: High schools could conduct pilot pedagogic experiments to determine the actual age-feasibility and age-appropriateness of all analytic knowledge content related to engineering materials identified in Tables 2A through 2E, using the selected Textbooks 1 through 5; and K-12 mathematics and science teachers could use the same Tables 2A through 2E as references to incorporate engineering materials topics into respective curriculum; and (2) **Curriculum development**: Existing K-12 engineering and technology curriculum developers could use the Tables 2A through 2E as references for the development of new K-12 engineering instructional materials or for the incorporation of engineering materials-related knowledge and skills into their previously developed instructional materials.

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About the Author:

Edward Locke is a product designer, CADD specialist, digital graphic artist, and independent scholar on K12 STEAM issues. He taught engineering graphics and CADD technology with product design projects to students from diverse ethnic backgrounds (Latino, Vietnamese-, African-, Caucasian-Americans, and others) at Santa Ana College, California (2000-2007) as an adjunct instructor, practiced product design and graphic design (1994-2014), pursued graduate studies at California State University Los Angeles (2004-2007) and then at the University of Georgia as a National Center for Engineering and Technology Education Fellow (2007-2009). He graduated in 2009 with an Education Specialist degree from the College of Education, Department of Workforce Education, Leadership and Social Foundations at The University of Georgia, Athens. He is currently working on issues of K12 engineering and technology curriculum, in collaboration with professors of the Engineering Department, at East Los Angeles College; and he could be reached at edwardnlocke@yahoo.com. Edward Locke's professional works, college-level textbooks and instructional materials, as well as research writings and curriculum development documents are featured in his four websites: (1) Scholar STEAM K12 Plus (K12 engineering and technology curriculum at http://scholarsteamk12plus.weebly.com/), (2) SuniSea Products (consumer product design, engineering graphics and CADD technology at http://suniseaproducts.weebly.com/), (3) SuniSea Design (graphic design and visual communication at http://suniseadesign.weebly.com/), and (4) SuniSea Creation (traditional and digital arts at http://suniseacreation.weebly.com/).

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