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

Presenting a List of High School 9th Grade Age-Possible Statics and Fluid Mechanics Topics and Estimating the Time Slot Needed for Their Coverage in High School Schedule

Edward Locke

(edwardnlocke@yahoo.com)

Abstract

As a sequel to the author's previously published article in the Winter 2009 issue of *The Journal of Technology Studies* (Locke, 2009a), this article is intended to present (1) a list of topics which have been determined to be possible for trial-out with 9th Grade students, from the subjects of statics and fluid mechanics, two common major courses in a typical university undergraduate engineering program, using a practical conceptual framework that has been previously explained (Locke, 2009a, pp. 26-27); and (2) a preliminary conceptual framework for estimating the allocation of time needed for the incorporation of engineering topics into high school curriculum, drawing reference from the way topics of mathematics, physics and chemistry have been assigned to different grade-levels for different allocation of time.

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 (Statics and Fluid Mechanics)

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, 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 (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, Table 1); (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.

Sources of Data

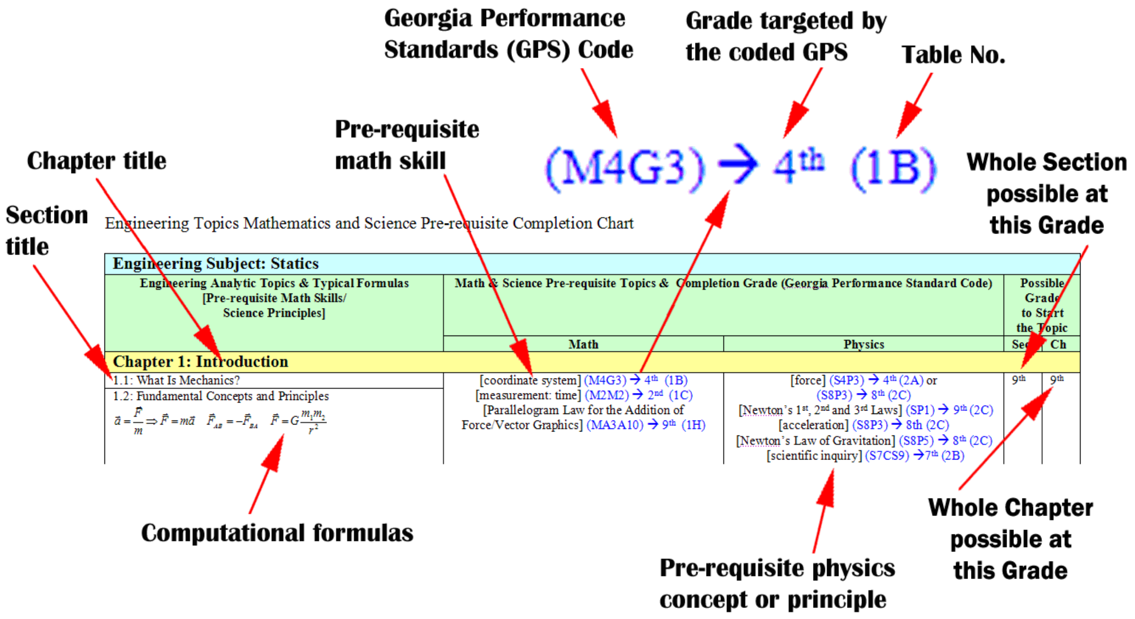
Table 1 lists (1) the college-level textbooks used for the extraction of statics and fluid mechanics related engineering analytic/predictive principles and computational formulas, and (2) the instructor's or student's solution manuals used to double-check for the mathematics and physics principles and computational skills needed for the study of various topics of statics and fluid mechanics contained in the main textbook.

Table 1. Data Source (Statics and Fluid Mechanics Instructional Materials)

	For Statics		
	Main Textbook	**Instructor's Solution Manuals**	
Title	Vector Mechanics for Engineers Statics, 7th Edition	Instructor's and Solutions Manual to Accompany Vector Mechanics for Engineers - Statics, 7th Ed., Vol. 1	Instructor's and Solutions Manual to Accompany Vector Mechanics for Engineers - Statics, 7th Ed., Vol. 2
Authors	Ferdinand P. Beer, E. Russell Johnston, and Elliot R. Eisenberg	Ferdinand P. Beer, E. Russell Johnston, and Elliot R. Eisenberg	Ferdinand P. Beer, E. Russell Johnston, and Elliot R. Eisenberg
Publisher	McGraw-Hill Higher Education	McGraw-Hill Higher Education	McGraw-Hill Higher Education
Year	2004	2004	2004
ISBN	0-07-230493-6	10: 0072536055	10: 0072962623
	For Fluid Mechanics		
	Main Textbook	**Student Solution Manual**	**Reference Book**
Title	Fundamentals of Fluid Mechanics, 5th Edition	A Brief Introduction to Fluid Mechanics, Student Solutions Manual, 4th Ed.	A Brief Introduction to Fluid Mechanics, 4th Ed.
Authors	Bruce M. Munson, Donald F. Young, and Theodore H. Okiishi	Donald F. Young, Bruce R. Munson, Theodore H. Okiishi, Wade W. Huebsch	Donald F. Young, Bruce R. Munson, Theodore H. Okiishi, Wade W. Huebsch
Publisher	John Wiley & Sons, Inc.	John Wiley & Sons, Inc.	John Wiley & Sons, Inc.
Year	2006	2007	2007
ISBN	0-471-67582-2	978-0470099285	978-0470039625

Initial Determination of High School Age-Possible Statics and Fluid Mechanics Topics

The outcome of this research is very encouraging. Tables 2A and 2B indicate that: (1). for statics, 58.7% of all sections, and 58.2% of the volume in the selected textbook is based on pre-calculus mathematics and on principles of physics students are supposed to learn before or by 9th Grade, according to my interpretation of the mandates of the Mathematics and Science Performance Standards of the State of Georgia Department of Education; (2). for fluid mechanics, 62.2% of all sections, and 51.0% of the volume in the selected textbook is based on pre-calculus mathematics and on principles of physics students are supposed to learn before or by 9th Grade, according to the same mandates.



Engineering Topics Mathematics and Science Pre-requisite Completion Chart

Engineering Subject: Statics				
Engineering Analytic Topics & Typical Formulas [Pre-requisite Math Skills/ Science Principles]	Math & Science Pre-requisite Topics & Completion Grade (Georgia Performance Standard Code)		Possible Grade to Start the Topic	
	Math	Physics	Sec	Ch
Chapter 1: Introduction				
1.1: What Is Mechanics? 1.2: Fundamental Concepts and Principles $\vec{a}=\frac{\vec{F}}{m}\Rightarrow\vec{F}=m\vec{a}\quad\vec{F}_{AB}=-\vec{F}_{BA}\quad\vec{F}=G\frac{m_1m_2}{r^2}$	[coordinate system] (M4G3) → 4th (1B) [measurement: time] (M2M2) → 2nd (1C) [Parallelogram Law for the Addition of Force/Vector Graphics] (MA3A10) → 9th (1H)	[force] (S4P3) → 4th (2A) or (S8P3) → 8th (2C) [Newton's 1st, 2nd and 3rd Laws] (SP1) → 9th (2C) [acceleration] (S8P3) → 8th (2C) [Newton's Law of Gravitation] (S8P5) → 8th (2C) [scientific inquiry] (S7CS9) → 7th (2B)	9th	9th

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

Initial Determination of Pre-Requisite Mathematics and Science Topics

Tables 3A, 3B, 4A, and 4B list the mathematics skills and science (physics and chemistry) principles needed to be reviewed or specially taught as pre-requisites for teaching statics and fluid mechanics topics to 9th Grade students; and they indicate that (a) for the basic pre-requisite mathematics topics, the numbers of Topics needed as pre-requisites are 13 for Statics (a lower-division undergraduate college course), 19 for Fluid Mechanics (an upper-division undergraduate college course), and 23 for both subjects; and those having the most frequent occurrences are four operations (35.8%), exponent (13.0%), areas of geometric shapes such as circle, triangle, etc (9.8%), trigonometric functions (9.8%), and square root (7.0%); (b) for more challenging pre-requisite mathematics topics, the numbers of Topics needed are 7 for Statics, 7 for Fluid Mechanics, and 13 for both subjects; and those having the most frequent occurrences are integration (18.1%), cross product (16.7%), trigonometric functions (16.7%), derivative (9.7%), sigma notation and summation (9.7%), and dot product (8.3%); (c) for the basic pre-requisite physics topics, the numbers of Topics needed are 7 for Statics, 18 for Fluid Mechanics, and 22 for both subjects; and those having the most frequent occurrences are velocity (18.6%), density (16.3%), force (15.4%), gravity (14.0%), speed (6.8%), and mass (6.3%); (d) for more challenging pre-requisite physics and chemistry topics, the numbers of Topics needed are 0 for Statics, 11 for Fluid Mechanics, and 11 for both subjects; and those having the most frequent occurrences are pressure (66. 7%) and friction (6. 7%). The above Topics cover only the very basic skills; and the most frequently needed ones are the very simple ones, such as four operations, exponent, areas of geometric shapes for mathematics skills, and velocity, density, force, gravity, speed, and mass for scientific principles. Therefore, we could tentatively but reasonably conclude that high school 9th Grade students have been prepared for pre-requisite mathematics skills and scientific principles, or could be taught some special ones, for studying certain number of engineering topics from both lower- and upper-division undergraduate engineering courses.

The Relative Validity of the Selection of "Age-Possible" Engineering Topics

Need for a new approach: Tables 2A and 2B are intended to be "initial lists" of high school 9th Grade "age-possible" statics and fluid mechanics topics; whether these topics are actually age-feasible or age-appropriate could be determined only upon completion of actual pedagogic pilot studies (including development of new instructional materials) and related research analysis. However, the presentation of these Tables could constitute the critical first step for the systematic, cohesive and extensive integration of statics- and fluid mechanics-related engineering analytic principles and predictive computational skills into a viable K-12 engineering and technology curriculum. Creating a K-12 engineering curriculum based on sequentially organized analytical principles and skills is a needed approach for strengthening K-12 STEM education in general; and to charter a new course, a lot of uncertainties are involved, and only through pilot studies could the validity of any new approach be proved. As pointed out by the Committee on K-12 Engineering Education report (2009, pp. 7-8; p. 151), no systematic and clear description of what engineering topics could or should be included in a viable K-12 engineering curriculum is currently available; thus, we could only rely on relevant experience from the past and use reasonable conceptual framework to try to initially but systematically determine what are age-possible for K-12 students, and let further classroom experience through pilot studies determine what are actually "feasible" or "appropriate;" nevertheless, determining what are "possible" should be the necessary first step in the creation of a viable K-12 engineering curriculum in the near future, although, due to lack of solid experimental data from the past, the "validity" of the above-mentioned method for determining K-12 age-possible engineering topics is "relative." For all practical purposes, what is needed now is to come up with a comprehensive set of "initial" lists of "possibly" engineering topics for all K-12 grade levels, then use the lists as references to develop K-12 engineering textbooks and other instructional materials, and then try them out in pilot-study classrooms to finally determine what are actually "appropriate." Furthermore, it is worth pointing out that even for the most popular and well-established engineering textbooks, the selection and inclusion of topics, concepts, principles, formulas and other technical details, although valid to very high extent thanks to the best endeavors of many well-established engineering practitioners and educators, and to many years of classroom trials, such validity is still relative; and yes, sometimes, these textbooks fail to include important things from real-world engineering practice. Therefore, we should have the will to start from relative validity as long as the framework of research is rational, and let further pilot study improve it.

Past experience: Although the incorporation of formula-based analytic knowledge content in K-12 engineering curriculum is so far insignificant and not systematic, even in the best example found, we have the following examples to support the idea that indeed, systemic incorporation of particular sets of formulas-based engineering analytic content knowledge into K-12 classroom, beyond mere focus on generic, "trial-and-error" type of "engineering design process" as what is predominantly practiced, is possible: (1) in the United States, a few schools, such as Gwinnett School of Mathematics, Science and Technology, a chartered high school in Duluth, Georgia, have tried in the past several years unique approach of teaching pre-calculus-level, solid engineering analytic knowledge content from the subjects of material science, statics and others to high school students, and thus, providing some empirical evidence that the development and implementation of a pre-calculus-level, solid engineering analytic knowledge is feasible; (2) in Australia, about 10% of high schools offer engineering programs designed and implemented to specifically lead students to a university level engineering program, with well-developed instruments for the evaluation of outcomes, such as the Higher School Certificate Examination; and the declarative content knowledge featured in these materials match the academic and professional depth of those pre-calculus portions of relevant engineering courses (such as structural analysis and design), which are commonly found in undergraduate engineering lower-division curriculum. (Locke, 2009b, pp. 1-5, 7-8, 18, 71-76, and 78-83).

Table 2A. Initial List of High School 9th Grade Age-Possible Statics Topics

Chapter/Section (From Vector Mechanics for Engineers Statics, 7th Edition, by Ferdinand P. Beer, E. Russell Johnston, and Elliot R. Eisenberg)	**Page Information**	
	Page Numbers	**Number of Pages**
Chapter 1: Introduction (pp. 1-13 → 13 pages sub-total. 6 sections out of 6)		
1.1: What Is Mechanics?	1-13	13
1.2: Fundamental Concepts and Principles		
1.3: Systems of Units		
1.4: Conversion from One System of Units to Another		
1.5: Method of Problem Solution		
1.6: Numerical Accuracy		
Chapter 2: Statics of Particles (pp. 15-63 → 49 pages. Sub-total: 15 sections out of 15)		
2.1: Introduction	15-63	49
2.2: Force on a Particle. Resultant of Two Forces		
2.3: Vectors		
2.4: Addition of Vectors		
2.5: Resultant of Several Concurrent Forces		
2.6: Resolution of a Force into Components		
2.7: Rectangular Components of a Force. Unit Vector		
2.8: Addition of Forces by Summing *x* and *y* Components		
2.9: Equilibrium of a Particle		
2.10: Newton's First Law of Motion		
2.11: Problems Involving the Equilibrium of a Particle. Free-Body Diagrams		
2.12: Rectangular Components of a Force in Space		
2.13: Force Defined by Its Magnitude and Two Points on Its Line of Action		
2.14: Addition of Concurrent Forces in Space		
2.15: Equilibrium of a Particle in Space		
Chapter 3: Rigid Bodies - Equivalent Systems of Forces (pp. 74-145 → 72 pages. Sub-total: 21 sections out of 21)		
3.1: Introduction	74-145	72
3.2: External and Internal Forces		
3.3: Principle of Transmissibility. Equivalent Forces		
3.4: Vector Product of Two Vectors		
3.5: Vector Products Expressed in Terms of Rectangular Components		
3.6: Moment of a Force about a Point		
3.7: Varignon's Theorem		
3.8: Rectangular Components of the Moment of a Force		
3.9: Scalar Product of Two Vectors		
3.10: Mixed Triple Product of Three Vectors		
3.11: Moment of a Force about a Given Axis		
3.12: Moment of a Couple		
3.13: Equivalent Couples		
3.14: Addition of Couples		
3.15: Couples Can Be Represented by Vectors		
3.16: Resolution of a Given Force Into a Force at *O* and a Couple		
3.17: Reduction of a System of Forces to One Force and One Couple		
3.18: Equivalent Systems of Forces		
3.19: Equipollent Systems of Vectors		
3.20: Further Reduction of a System of Forces		
3.21: Reduction of a System of Forces to a Wrench		
Chapter 4: Equilibrium of Rigid Bodies (pp. 158-210 → 53 pages. Sub-total: 9 sections out of 9)		
4.1: Introduction	158-210	53
4.2: Free-Body Diagram		
4.3: Reactions at Supports and Connections for a Two-Dimensional Structure		
4.4: Equilibrium of a Rigid Body in Two Dimensions		
4.5: Statically Indeterminate Reactions. Partial Constraints		
4.6: Equilibrium of a Two-Force Body		
4.7: Equilibrium of a Three-Force Body		
4.8: Equilibrium of a Rigid Body in Three Dimensions		
4.9: Reactions at Supports and Connections for a Three-Dimensional Structure		

Table 2A. (Continued)

Chapter/Section (From Vector Mechanics for Engineers Statics, 7th Edition, by Ferdinand P. Beer, E. Russell Johnston, and Elliot R. Eisenberg)	**Page Information**	
	Page Numbers	**Number of Pages**
Chapter 5: Distributed Forces: Centroids & Centers of Gravity (pp. 219-273 → 55 pages. Sub-total: 0 sections out of 11)		
Chapter 6: Analysis of Structures (pp. 284-342 → 59 pages sub-total. 12 sections out of 12)		
6.1: Introduction	284-342	59
6.2: Definition of a Truss		
6.3: Simple Trusses		
6.4: Analysis of Trusses by the Method of Joints		
6.5: Joints under Special Loading Conditions		
6.6: Space Trusses		
6.7: Analysis of Trusses by the Method of Sections		
6.8: Trusses Made of Several Simple Trusses		
6.9: Structures Containing Multiforce Members		
6.10: Analysis of a Frame		
6.11: Frames Which Cease to Be Rigid When Detached from Their Supports		
6.12: Machines		
Chapter 7: Forces in Beams and Cables (pp. 353-401 → 49 pages. Sub-total: 0 sections out of 10)		
Chapter 8: Friction (pp. 411-460 → 50 pages sub-total. 10 sections out of 10)		
8.1: Introduction	411-460	42
8.2: The Laws of Dry Friction. Coefficients of Friction		
8.3: Angles of Friction		
8.4: Problems Involving Dry Friction		
8.5: Wedges		
8.6: Square-Threaded Screws		
8.7: Journal Bearings. Axle Friction		
8.8: Thrust Bearings. Disk Friction [2]		
8.9: Wheel Friction. Rolling Resistance		
8.10: Belt Friction [2]		
Chapter 9: Distributed Forces: Moments of Inertia (pp. 471-544 → 74 pages. Sub-total: 0 sections out of 18)		
Chapter 10: Method of Virtual Work (pp. 557-591→ 35 pages sub-total. 0 sections out of 9)		

Statistical Summary

Total Numbers	**Number of Pages in the Body Text**	**Time Allocation Points (TAP)** [1]					
		S	**C**	**IE**	**GE**	**F**	**T**
	288	71	66	142	103	135	4

Total Number of Pages Covered by Text (Excluding "Review and Summary for Chapters," "Review Problems" and "Computer Problems Sections): 509	**Total Numbers of Sections Covered Under All Chapters:** 71 out of 121
Percentage of Pre-Calculus Sections $\%_{\text{Pre-Calculus}} = \left(\dfrac{\text{Number of Pre-Calculus Sections}}{\text{Total Number of Sections}}\right)(100\%)$ $= \left(\dfrac{71}{121}\right)(100\%) = 58.7\%$	**Percentage of Chapters with Pre-Calculus Sections** $\%_{\text{Pre-Calculus}} = \left(\dfrac{\text{Number of Chapters with Pre-Calculus Sections}}{\text{Total Number of Chapters}}\right)(100\%)$ $= \left(\dfrac{6}{10}\right)(100\%) = 60.0\%$
Total Numbers of Chapters Covered: 6 out of 10	**Total Number of Pages Covered by Pre-Calculus Portion:** 296 out of 509

Percentage of Pre-Calculus Volume:

$$\%_{\text{Pre-Calculus}} = \left(\frac{\text{Number of Pre-Calculus Pages}}{\text{Total Number of Pages}}\right)(100\%) = \left(\frac{296}{509}\right)(100\%) = 58.2\%$$

Notes:

[1] For Tables 2A, 2B, 5B and 6, the abbreviations in the Time Allocation Points (TAP) section stand for the following items covered in the "body text" of each Chapter:

S = Number of Sections and/or Sub-Sections; if a Section is not divided into Sub-Sections, then it is counted as 1; if a Section is divided into Sub-Sections, then the number of Sub-Sections is counted.

C = Number of new major concepts.

IE = Number of intermediate step equations in each Chapter, which are used to derive the governing or main formulas, or to explain the conversion of units, or to explain pertinent rules.

GE = Number of governing equations (or "formulas") used to solve homework or real-world problems.

F = Number of Figures.

T = Number of Tables used mostly to list constants, units, unit conversion factors, etc.

The details of data sources (except Section and/or Sub-Section which are self-explanatory) for the above items are listed in Table 5B.

[2] Section 8.8 contains 1formula with two-dimensional integral used to derive the main equations; Section 8.10 contains 2 formulas with 1st degree derivative and 1 formula with one-dimensional integral, also used to derive the main equations; removing these formulas from consideration will not affect the teaching and learning of these Sections to either college or high school students.

Table 2B. Initial List of High School 9th Grade Age-Possible Fluid Mechanics Topics

Chapter/Section (From Fundamentals of Fluid Mechanics, 5th Edition, by Bruce M. Munson, Donald F. Young, and Theodore H. Okiishi)	**Page Information**	
	Page Numbers	**Number of Pages**
Chapter 1 – Introduction (pp. 1-30 → 30 pages. Sub-total: 10 sections out of 11)		
1.1 Some Characteristics of Fluid	1-29	29
1.2 Dimensions, Dimensional Homogeneity, and Units		
1.3 Analysis of Fluid Mechanics Behavior		
1.4 Measures of Fluid Mechanics Mass and Weight		
1.4.1 Density		
1.4 2 Specific Weight		
1.4.3 Specific Gravity		
1.5 Ideal Gas Law		
1.6 Viscosity [2]		
1.7 Compressibility of Fluids		
1.7.1 Bulk Modulus		
1.7.2 Compression and Expansion of Gases		
1.7.3 Speed of Sound		
1.8 Vapor Pressure		
1.9 Surface Tension		
1.10 A Brief Look Back in History		
Chapter 2 Fluid Statics (pp. 38-79 → 42 pages. Sub-total: 9 sections out of 13)		
2.3 Pressure Variation in a Fluid at Rest [3]	42-57	16
2.3.1 Incompressible Fluid		
2.3.2 Compressible Fluid		
2.4 Standard Atmosphere		
2.5 Measurement of Pressure		
2.6 Monometry		
2.6.1 Piezometer Tube		
2.6.2 U-Tube Manometer		
2.6.3 Inclined-Tube Manometer		
2.7 Mechanical and Electronic Pressure Measuring Devices		
2.9 Pressure Prism	63-73	11
2.10 Hydrostatic Force on a Curves Surface		
2.11 Buoyancy, Flotation, and Stability		
2.11.1 Archimedes' Principle		
2.11.2 Stability		
Chapter 3 Elementary Fluid Dynamics - The Bernoulli Equation (pp. 95-135 → 41 pages. Sub-total: 8 sections out of 9)		
3.1 Newton's Second Law	95-101	7
3.2 F = ma along a Streamline		
3.4 Physical Interpretation	104-134	31
3.5 Static, Stagnation, Dynamic, and Total Pressure		
3.6 Examples of Use of the Bernoulli Equation		
3.6.1 Free Jets		
3.6.2 Confined Flows		
3.6.3 Flowrate Measurement		
3.7 The Energy Line and the Hydraulic Grade Line		
3.8 Restrictions on Use of the Bernoulli Equation		
3.8.1 Compressibility Effects		
3.8.3 Rotational Effects		
3.8.4 Other Restrictions		
Chapter 4 Fluid Kinematics (pp. 150-184 → 35 pages. Sub-total: 3 sections out of 5)		
4.3 Control Volume and System Representations	168-171	4
4.4 The Reynolds Transport Theorem		
4.4.7 Selection of a Control Volume	182-183	2
Chapter 5 Finite Control Volume Analysis (pp. 192-252 → 61 pages. Sub-total: 2 sections out of 5)		
5.1 Conservation of Mass - The Continuity Equation [4]	195-200	6
5.1.2 Fixed, Non-deforming Control Volume		
5.3 First Law of Thermodynamics	229-246	18
5.3.3 Comparison of the Energy Equation with the Bernoulli Equation		
5.3.4 Application of the Energy Equation to Non-uniform Flow		
5.3.5 Combination of the Energy Equation and the Moment-of-momentum Equation		
5.4.4 Application of the Loss Form of the Energy Equation	249-251	3

Table 2B. (Continued)

Chapter/Section (From Fundamentals of Fluid Mechanics, 5th Edition, by Bruce M. Munson, Donald F. Young, and Theodore H. Okiishi)	**Page Information**	
	Page Numbers	**Number of Pages**
Chapter 6 Differential Analysis of Fluid Flow (pp. 272-334 → 63 pages. Sub-total: 0 sections out of 11)		
Chapter 7 Similitude, Dimensional Analysis, and Modeling (pp. 346-391 → 46 pages sub-total. 1 sections out of 11) [5]		
7.1 Dimensional Analysis	346-349	4
Chapter 8 Viscous Flow in Pipes (pp. 401-472 → 72 pages. Sub-total: 5 sections out of 7)		
8.1 General Characteristics of Pipe Flow	401-407	7
8.1.1 Laminar or Turbulent Flow		
8.1.2 Entrance Region and Fully Developed Flow		
8.1.3 Pressure and Shear Stress		
8.2 Fully Developed Laminar Flow	416-417	2
8.2.4 Energy Considerations		
8.4 Dimensional Analysis of Pipe Flow	430-471	42
8.4.1 Major Losses		
8.4.2 Minor Losses		
8.4.3 Noncircular Conduits		
8.5 Pipe Flow Examples		
8.5.1 Single Pipes		
8.5.2 Multiple Pipe Systems		
8.6 Pipe Flowrate Measurement		
8.6.1 Pipe Flowrate Meters		
8.6.2 Volume Flow Meters		
Chapter 9 Flow over Immersed Bodies (pp. 483-550 → 68 pages. Sub-total: 4 sections out of 5)		
9.1 General External Flow Characteristics	483-493	11
9.1.1 Lift and Drag Concepts		
9.1.2 Characteristics of Flow Past an Object		
9.3 Drag	518-549	32
9.3.1 Friction Drag		
9.3.2 Pressure Drag		
9.3.3 Drag Coefficient Data and Examples		
9.4 Lift		
9.4.1 Surface Pressure Distribution		
9.4.2 Circulation		
Chapter 10 Open Channel Flow (Whole Chapter; pp. 561-605 → 45 pages. Sub-total: 7 sections out of 7)		
10.1 General Characteristics of Open-Channel Flow	561-603	43
10.2 Surface Waves		
10.2.1 Wave Speed		
10.2.2 Froude Number Effects		
10.3 Energy Considerations		
10.3.1 Specific Energy		
10.4 Uniform Depth Channel Flow		
10.4.1 Uniform Flow Approximations		
10.4.2 The Chezy and Manning Equations		
10.4.3 Uniform Depth Examples		
10.5 Gradually Varied Flow		
10.5.1 Classification of Surface Shapes		
10.5.2 Examples of Gradually Varied Flows		
10.6 Rapidly Varied Flow		
10.6.1 The Hydraulic Jump		
10.6.2 Sharp-Crested Weirs		
10.6.3 Broad-Crested Weirs		
10.6.4 Underflow Gates		
Chapter 11 Compressible Flow (pp. 614-678 → 65 pages. Sub-total: 6 sections out of 8)		
11.1 Ideal Gas Relationships [6]	614-677	64
11.2 Mach Number and Speed of Sound [6]		
11.3 Categories of Compressible Flow		
11.4 Isentropic Flow of an Ideal Gas		
11.4.2 Converging-Diverging Duct Flow		
11.4.3 Constant Area Duct Flow		

Table 2B. (Continued)

Chapter/Section (From Fundamentals of Fluid Mechanics, 5th Edition, by Bruce M. Munson, Donald F. Young, and Theodore H. Okiishi**)**	**Page Information**	
	Page Numbers	**Number of Pages**
Chapter 11 Compressible Flow (pp. 614-678 → 65 pages. Sub-total: 6 sections out of 8) (Continued)		
11.5 Non-isentropic Flow of an Ideal Gas	↑	↑
11.5.1 Adiabatic Constant Area Duct Flow with Friction (Fanno Flow) [6]		
11.5.2 Frictionless Constant Area Duct Flow with Heat Transfer (Rayleigh Flow) [4]		
11.5.3 Normal Shock Waves		
11.6 Analogy between Compressible and Open-Channel Flows		
11.7 Two-Dimensional Compressible Flow		
Chapter 12 Turbomachines (Whole Chapter; pp. 684-736 → 53 pages. Sub-total: 9 sections out of 10)		
12.1 Introduction	684-734	51
12.2 Basic Energy Considerations		
12.3 Basic Angular Momentum Considerations		
12.4 The Centrifugal Pump		
12.4.1 Theoretical Considerations		
12.4.2 Pump Performance Characteristics		
12.4.3 Net Positive Suction Head (NPSH)		
12.4 4 System Characteristics and Pump Selection		
12.5 Dimensionless Parameters and Similarity Laws		
12.5.1 Special Pump Scaling Laws		
12.5.2 Specific Speed		
12.5.3 Suction Specific Speed		
12.6 Axial-Flow and Mixed-Flow Pump		
12.7 Fans		
12.8 Turbines		
12.8.1 Impulse Turbines		
12.8.2 Reaction Turbines		
12.9 Compressible Flow Turbomachines		
12.9.1 Compressors		
12.9.2 Compressible Flow Turbines		
Appendix B Physical Properties of Fluids	N/A	
Appendix C Properties of the U.S. Standard Atmosphere		
Appendix D Compressible Flow Graphs for an Ideal Gas (k = 1.4)		
Appendix E Compressive Table of Conversion Factors		

Summary

Total Numbers	**Number of Pages in the Body Text**	**Time Allocation Points (TAP)** [1]					
		S	**C**	**IE**	**GE**	**F**	**T**
	383	124	114	515	161	268	18

Statistical Summary

	Number of Pages	**Time Allocation Points (TAP)** [1]					
		S	**C**	**IE**	**GE**	**F**	**T**
Total Number	288	71	66	142	103	135	4

Total Number of Pages Covered by Text (Excluding "Problems" Section)	621
Total Numbers of Sections Covered Under All Chapters	64 out of 102

Percentage of Pre-Calculus Sections

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

$$= \left(\frac{64}{102}\right)(100\%) = 62.7\%$$

Percentage of Chapters with Pre-Calculus Sections

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

$$= \left(\frac{10}{12}\right)(100\%) = 83.3\%$$

Total Numbers of Chapters Covered	10 out of 12
Total Number of Pages Covered by Pre-Calculus Portion	317

Percentage of Pre-Calculus Volume

$$\%_{\text{Pre-Calculus}} = \left(\frac{\text{Number of Pre-Calculus Pages}}{\text{Total Number of Pages}}\right)(100\%) = \left(\frac{317}{621}\right)(100\%) = 51.0\%$$

Table 2B. (Continued)

Chapter/Section (From Fundamentals of Fluid Mechanics, 5th Edition, by Bruce M. Munson, Donald F. Young, and Theodore H. Okiishi**)**
Notes: [1] For Tables 2A, 2B, 5B and 6, the abbreviations in the Time Allocation Points (TAP) section stand for the same items listed in the Notes section of Table 2A; and the details of data sources for the above items are listed in Table 5B. [2] The main formulas in Section1.6 are based on pre-calculus mathematics skills; a couple of formulas are written in derivative form but could be changed to division form. [3] Basic principles in Section 2.3 could be explored; some Governing Equations are pre-calculus based while others are calculus-based. [4] Basic concepts in Section 5.1 could be explored, although most of the Governing Equations are calculus-based. [5] The majority of Sections and Sub-Sections in Chapter 7, except 7.10 (Similitude), are based on pre-calculus mathematics; however, the type of “abstract thinking” required to understand and to apply the content knowledge appears to be most likely beyond the cognitive developmental maturity level of high school students; therefore, only the basic concept of dimensional analysis in Section 7.1 is recommended for exploration. [6] For Sections 11.1, 11.2, and 11.5.1, most of the Governing Equations are based on pre-calculus mathematics skills, although some of the Intermediate Equations used to derive Governing Equations are calculus-based.

Incorporation and Integration of Engineering Topics into K-12 Curriculum

Two Practical Approaches for Incorporating Engineering Topics into K-12 Curriculum

Pre-engineering courses may interest some high school technology education teachers but not necessarily most others, for a number of possible reasons, including (1) conflict of interests (high school mathematics and science teachers need to focus on getting students to pass mandated examinations for graduation and do not want interference from other “mandates,” or from time-consuming “trial-and-error” engineering design projects that have little connection to traditional mathematics and science pedagogy); (2) lack of well-developed high school engineering curriculum and instructional materials that are solidly based on analytic and predictive principles and skills, i.e., the understanding of concepts and the use of formulas to solve problems (students often ask “what is the formula?”); (3) lack of well-developed K-12 engineering teacher education program. Thus, a great deal of preparatory groundwork is badly needed before “most others” or even the majority of high school technology education teachers could be interested in it. However, in order to improve K-12 STEM education in general and to solve the chronic problem of shortage in engineering graduates in the United States (approximately 60,000 to 80,000 per year in the recent decade), some pioneering endeavors are worth considering. The presentation of the “initial lists” of 9th grade age-possible statics and fluid mechanics topics (Tables 2A and 2B) and of relevant pre-requisite mathematics and science principles and skills (Tables 3A, 3B, 4A and 4B) could contribute to the solution of these problems, by providing a practical reference for the systematic and cohesive integration of K-12 age-possible engineering topics (from the subjects of statics and fluid mechanics) into existing K-12 curriculum, with the following applications: (1) <u>K-12 engineering curriculum development</u>: Current K-12 engineering and technology curriculum developers and teachers, in collaboration with mathematics and science teachers, could use the above Tables as references in the selection of statics and fluid mechanics topics from the main textbook listed in Table 1, for the development of instructional materials, and for pedagogic pilot study aimed at determining if the topics included in these Tables are indeed age-feasible and age-appropriate; and (2) <u>Engineering education</u>: K-12 engineering teachers as well as university undergraduate engineering professors could use the Tables as references to review pertinent mathematics skills and scientific principles at the start of engineering courses with their students, for the pre-calculus portions of statics and fluid mechanics topics. There are two possible methods for the integration of K-12 age-possible engineering topics into the existing K-12 STEM curriculum:

1. Partial incorporation into existing K-12 mathematics and science courses: Incorporating engineering topics, with concepts, analytical principles and formula-based skills, in K-12 mathematics, science and technology courses, into existing mathematics courses as examples of real-world application of mathematics skills and scientific principles, is a flexible and realistic approach for the present time; and it does not need to drastically restructure existing K-12 STEM Education framework. In many places in the United States, this approach has been implemented as extra-credit learning activities, summer camps projects, etc., to enrich or strengthen the existing courses while introducing students to the fields of engineering. In this case, time allocation is very flexible; it is up to instructors of existing courses to determine how many topics to incorporate and how much time to spend. The major shortcoming is that it is difficult to use this approach to systematically, cohesively and extensively incorporate engineering content knowledge into K-12 curriculum as a fully developed component.

2. Incremental expansion of existing K-12 technology curriculum into a new K-12 engineering and technology curriculum with full development of high school engineering courses: A more futuristic but still possible approach that could offer a long-term solution to the problem of chronicle shortage of U.S. engineering enrollment would be the one advocated in my previously published article (Locke, 2009, p.28), which would offer K-12 students an Engineering and Technology Pathway, with fully developed technology courses at Grades 6-8 (middle school) and engineering courses at Grades 9-12 (high school). This approach would move the basic technology courses (such as drafting and manufacturing technology) currently offered across high schools in the United States to middle schools; these basic technology courses do NOT require high school level mathematics skills or physics and chemistry principles beyond what are covered in elementary school science courses, and in addition, some of them, such as engineering drafting, have been tried at many middle schools in the United States with proven success; therefore, it is feasible to bring them down to middle school level so as to make room at high school level for the development and implementation of engineering courses. In this case, the existing K-12 Technology Education framework could be naturally and incrementally evolved into the future K-12 Engineering and Technology Education framework; such incremental but revolutionary transition could be considered due to the fact that we are living in the Age of Globalization, there is an increasing tendency of outsourcing technology jobs to less developed countries, and an increasing need for engineers and scientists to create innovative products and systems in the United States; therefore, this transition is in line with actual societal needs although visionary. In the development of engineering courses, existing physics and chemistry courses could serve as reference frameworks due to the fact that engineering is an integration of applied STE (science, notably physics and chemistry, technology, such as CAD, and mathematics) and creative design process. To estimate the allocation of time needed for the incorporation of engineering topics into high school curriculum with fully developed courses, a practical conceptual framework has been constructed.

Table 3A. Basic Mathematics Skills to be Reviewed or Taught Before Teaching the Pre-Calculus Portions of Statics and Fluid Mechanics Subjects to 9th Graders

Topics to be Reviewed or Taught (From Larger to Smaller % of Occurrences for Both Subjects)		**For Statics** (13 Topics)		**For Fluid Mechanics** (19 Topics)		**For Both Statics & Fluid Mechanics** (23 Topics)	
		Number of Occurrences	**%**	**Number of Occurrences**	**%**	**Number of Occurrences**	**%**
1	four operations	28	32.2	74	37.4	102	35.8
2	exponent	6	6.9	31	15.7	37	13.0
3	areas of geometric shapes: circle, triangle, etc.	1	1.1	27	13.6	28	9.8
4	trigonometric functions	14	16.1	14	7.1	28	9.8
5	square root	4	4.6	16	8.1	20	7.0
6	coordinate system	15	17.2	1	0.5	16	5.6
7	sigma notation and summation	9	10.3	4	2.0	13	4.6
8	volume	0	0	9	4.5	9	3.2
9	geometry: point, axis/line, 3D body	5	5.7	0	0	5	1.8
10	ratio	0	0	4	2.0	4	1.4
11	unit conversion	1	1.1	3	1.5	4	1.4
12	graph	0	0	3	1.5	3	1.1
13	partial derivatives	0	0	3	1.5	3	1.1
14	triangle	0	0	3	1.5	3	1.1
15	height	0	0	2	1.0	2	0.7
16	cylinder	0	0	1	0.5	1	0.4
17	measurement: time	1	1.1	0	0	1	0.4
18	percent	1	1.1	0	0	1	0.4
19	perimeter	0	0	1	0.5	1	0.4
20	problem-solving	1	1.1	0	0	1	0.4
21	Pythagorean Theorem	0	0	1	0.5	1	0.4
22	radius	0	0	1	0.5	1	0.4
23	surface	1	1.1	0	0	1	0.4
Total Number of Occurrences		87	100	198	100	285	100

Table 3B. More Challenging Mathematics Skills to be Reviewed or Taught Before Teaching the Pre-Calculus to Beginning Calculus Portions of Statics and Fluid Mechanics Subjects to 9th Graders

Topics to be Reviewed or Taught as Special Lessons (From Larger to Smaller % of Occurrences for Both Subjects)		**For Statics** (7 Topics)		**For Fluid Mechanics** (7 Topics)		**For Both Statics & Fluid Mechanics** (13 Topics)	
		Number of Occurrences	**%**	**Number of Occurrences**	**%**	**Number of Occurrences**	**%**
1	integration	0	0	13	44.8	13	18.1
2	cross product	11	25.6	1	3.4	12	16.7
3	trigonometric functions	12	27.9	0	0	12	16.7
4	derivative	0	0	7	24.1	7	9.7
5	sigma notation and summation	7	16.3	0	0	7	9.7
6	dot product	6	14.0	0	0	6	8.3
7	vector graphics	4	9.3	0	0	4	5.6
8	logarithmic functions	0	0	3	10.3	3	4.2
9	analytic geometry	0	0	2	6.9	2	2.8
10	ellipse	0	0	2	6.9	2	2.8
11	linear algebra	2	4.7	0	0	2	2.8
12	analytic geometry: hyperbolic tangent	0	0	1	3.4	1	1.4
13	Parallelogram Law for the Addition of Force/Vector Graphics	1	2.3	0	0	1	1.4
Total Number of Occurrences		43	100	29	100	72	100

Table 4A. Basic Physics Topics to Be Reviewed Before Teaching the Pre-Calculus Portions of Statics and Fluid Mechanics Subjects to 9th Graders

Topics to be Reviewed (From Larger to Smaller % of Occurrences for Both Subjects)		**For Statics** (7 Topics)		**For Fluid Mechanics** (18 Topics)		**For Both Statics & Fluid Mechanics** (22 Topics)	
		Number of Occurrences	**%**	**Number of Occurrences**	**%**	**Number of Occurrences**	**%**
1	velocity	0	0	41	21.6	41	18.6
2	density	0	0	36	18.9	36	16.3
3	force	16	51.6	18	9.5	34	15.4
4	gravity	0	0	31	16.3	31	14.0
5	speed	0	0	15	7.9	15	6.8
6	mass	0	0	14	7.4	14	6.3
7	temperature	0	0	8	4.2	8	3.6
8	Newton’s 1st, 2nd and 3rd Laws	6	19.4	2	1.1	8	3.6
9	acceleration	2	6.5	3	1.6	5	2.3
10	momentum	0	0	5	2.6	5	2.3
11	energy	0	0	4	2.1	4	1.8
12	graph	0	0	3	1.6	3	1.4
13	motion	3	9.7	0	0	3	1.4
14	power	0	0	3	1.6	3	1.4
15	weight	0	0	3	1.6	3	1.4
16	lever	2	6.5	0	0	2	0.9
17	heat	0	0	1	0.5	1	0.5
18	molecule	0	0	1	0.5	1	0.5
19	Newton’s Law of Gravitation	1	3.2	0	0	1	0.5
20	potential energy	0	0	1	0.5	1	0.5
21	scientific inquiry	1	3.2	0	0	1	0.5
22	work	0	0	1	0.5	1	0.5
Total Number of Occurrences		31	100	190		221	100

Table 4B. More Challenging Physics and Chemistry Topics to be Reviewed or Taught Before Teaching the Pre-Calculus Portions of Statics and Fluid Mechanics Subjects to 9th Graders

Topics to be Reviewed or Taught as Special Lessons (From Larger to Smaller % of Occurrences for Both Subjects)		**For Statics** (0 Topics)		**For Fluid Mechanics** (11 Topics)		**For Both Statics & Fluid Mechanics** (11 Topics)	
		Number of Occurrences	**%**	**Number of Occurrences**	**%**	**Number of Occurrences**	**%**
1	pressure	0	N/A	30	66.7	30	66. 7
2	friction	0	N/A	3	6.7	3	6. 7
3	{absolute temperature}	0	N/A	2	4.4	2	4.4
4	{Ideal Gas Law}	0	N/A	2	4.4	2	4.4
5	Newton’s 1st, 2nd and 3rd Laws	0	N/A	2	4.4	2	4.4
6	{gas/liquid}	0	N/A	1	2.2	1	2.2
7	{molecular and intermolecular cohesive force}	0	N/A	1	2.2	1	2.2
8	Reynold Number	0	N/A	1	2.2	1	2.2
9	speed of sound	0	N/A	1	2.2	1	2.2
10	stress	0	N/A	1	2.2	1	2.2
11	torque	0	N/A	1	2.2	1	2.2
Total Number of Occurrences		0	N/A	45	100	45	100

Table 5A. Data Source (Middle and High School Textbooks for the Courses of Algebra I, Geometry, Trigonometry, Physics, and Chemistry, Used at Esteban Torres High School, 4211 Dozier Street, Los Angeles, California 90063)

Course	Title, Authors, Publisher, Year & ISBN	Grade Level in California	Time Allocation
Physics	Holt California Physics, by Raymond A, Serway & Jerry S. Faughn; New York: Holt, Reinehart & Winston, A Harcourt Education Company, 2007, ISBN 0-03-092210-0	10th or 11th Grade	One Semester (20 Weeks)
Chemistry	Holt California Chemistry, by R. Thomas Myers, Keith B. Oldham, & Salvatore Tocci; New York: Holt, Reinehart & Winston, A Harcourt Education Company, 2007, ISBN 0-03-092204-6	11th Grade student	One Semester (20 Weeks)
Algebra I	California Algebra 1 Concepts, Skills, and Problem Solving, by Berchie Holiday, Beatrice Luchin, Gilbert J. Cuevas, John A. Carter, Daniel Marks, Roger Day, Ruth M. Casey, Linda M. Hayek, Columbus, OH: McGraw Hill, 2005, ISBN 978-0-07-877852-0	Mandatory at 8th Grade and can be taken at 9th Grade	One year or two semesters (20 Weeks-long)
Geometry	Intermediate Algebra, 8th Edition, by Charles P. McKeague, Belmont, CA: Brooks/Coe Cengage Learning, 2008, ISBN 13:978-0-495-10840-5	Recommended for 9th Grade and mandatory for high school graduation	One year or two semesters (20 Weeks-long)
Trigonometry	Precalculus with Trigonometry Concepts and Applications, 2nd Edition, by Paul A. Foerster, Emeryville, CA: Key Curriculum Press, 2007, ISBN 978-1-55953-788-9	Recommended as an elective for 11th Grade	One year or two semesters (20 Weeks-long)

A Practical Conceptual Framework for Estimating the Allocation of Time Needed for Teaching Engineering Topics to High School Students

"How long it would take to teach the statics and fluid mechanics topics considered as age-possible for 9th Grade students?" To answer this question, a practical conceptual framework has been constructed based on my personal experience as a former K-12 and college student, K-12 engineering design activity instructor and community college engineering instructor, using (1) the structural components of relevant high school and college textbooks, and (2) the classroom experience in learning and teaching STEM knowledge content, as data sources for qualitative and quantitative analysis, leading to the practical estimates of the allocation of time needed for the incorporation of the 9th Grade "age-possible" statics and fluid mechanics topics into high school curses:

1. The structural components of relevant textbooks: High school textbooks used in California for Algebra I, Geometry, Trigonometry, Physics and Chemistry courses (Table 5A) have been thoroughly analyzed page by page to count the numbers of the following components, which all take time to understand, learn and teach the course materials: (1) Sections, (2) Concepts or principles use to explain mathematics rules or scientific phenomena, (3) Intermediate Equations used to derive the governing or main formulas, (4) Governing Equations or important formulas used to solve homework and real-world problems, (5) Figures used to illustrate concepts or principles, (6) Tables used to list constants, units and conversion factors, or to compare concepts, rules, phenomena and others. For different textbooks, the above components take different names or designations, as explained in Table 5B. The numbers counted for the above items are designated as Time Allocation Points (TAP) in the construction of the practical conceptual framework for the Estimated Time Allocation (ETA) needed to incorporate high school age-possible engineering topics.

2. The classroom experience: Among the above 6 components, the allocations of time needed for each of the components in order to understand, learn and teach STEM knowledge

content covered in the textbooks are different; for example, based on the past learning and teaching experience, it would take more time to understand concepts and equations and to apply the governing equation in the solution of homework or real-world problems than to understand the figures and tables; therefore, for all practical purposes, the numbers of these more time-consuming components are conveniently increased by multiplication with a scale-up factor: (1) the number of Concepts is multiplied by 10 (it requires more time to understand scientific concepts and principles than to interpret the meanings of other items such as tables and figures, etc.); (2) the number of Governing Equations is multiplied by 10 (it requires greater amount of time to understand how the Governing Equations are used in the solution of problems, through many homework problems as well as real-world like projects). The assignment of scale-up factors is subjective; however, it is based on more or less rational interpretation of past experience, and does provide a more or less uniform criteria for the construction of the practical conceptual framework to be used in the estimate of the allocation of time needed for the incorporation of engineering topics into high school STEM curriculum. The total numbers of TAP (Time Allocation Points) for each of the high school mathematics and science textbooks could be compared with those for the statics or fluid mechanics textbooks, to obtain an Estimated Time Allocation (TA) needed for the incorporation of statics or fluid mechanics topics into fully developed high school engineering courses, using the ratio of

$$\frac{\sum \mathrm{TAP}_{\substack{\text{High School}\\ \text{Math/Science Textbook}}}}{\sum \mathrm{TAP}_{\substack{\text{College}\\ \text{Engineering Textbook}}}} = \frac{\mathrm{TA}_{\substack{\text{Current High School}\\ \text{Math/Science Course}}}}{\mathrm{ETA}_{\substack{\text{Future High School}\\ \text{Engineering Course}}}}$$

which leads to the equation of

$$\mathrm{ETA}_{\substack{\text{Future High School}\\ \text{Engineering Course}}} = \frac{\left(\mathrm{TA}_{\substack{\text{Current High School}\\ \text{Math/Science Course}}}\right)\left(\sum \mathrm{TAP}_{\substack{\text{College}\\ \text{Engineering Textbook}}}\right)}{\sum \mathrm{TAP}_{\substack{\text{High School}\\ \text{Math/Science Textbook}}}}.$$

Table 5B. Notes on the Data Sources for the Components Found in the "Body Text" and Used in the Counting of Time Allocation Points (TAP) for all Textbooks

Time Allocation Points (TAP)	**Relevant Component in College Engineering Textbooks**	
	Statics (Note: The "body text" does not include the Sample Problem, Solving Problems on Your Own, or Review and Summary for Chapter X sections)	**Fluid Mechanics** (Note: The "body text" does not include the Fluids in the News, Example X, Chapter Summary and Study Guide, References, Review Problems, and Problems sections)
Concepts (C)	Corresponding to the number of Sections (each Section, except Introduction, which covers a new major concept).	Number of Sections and/or Sub-Sections; each of them, except "Introduction," covers a new major concept.
Intermediate Equations (IE)	Number of intermediate step equations scattered in the body text and flash centered.	Number of intermediate step equations scattered in the body text and flash centered.
Governing Equations (GE)	Highlighted in yellow color.	Number of formulas used in the review problems in *A Brief Introduction to Fluid Mechanics 4th Edition Student Solutions Manual*; rounded up to the multiples of 5 to obtain a "safer" rough estimate.
Figures (F)	Number of Figures.	Number of Figures.
Tables (T)	Number of Tables.	Number of Tables.

Time Allocation Points (TAP)	**Relevant Component in High School Science Textbooks**	
	Physics (Note: The "body text" does not include the Sample Problem, Section Review, Practice, Highlights, Review, The Inside Story on X, Graphing Calculator Practice, Standardized Test Prep, Skills Practice Lab, Inquiry Lab, or Science-Technology-Society sections).	**Chemistry** (Note: The "body text" does not include the Section Review, Skills Toolkit, Sample Problem, Practice, Quick Lab, Consumer Focus, Element Spotlight, Chapter Highlights, Chapter Review, Standards Assessment, or Science and Technology, sections).
Concepts (C)	Concepts highlighted in yellow color.	Highlighted in yellow color.
Intermediate Equations (IE)	Scattered in the body text and flash centered.	Number of equations of particular chemical reactions and of unit conversion, flash centered.
Governing Equations (GE)	Scattered in the body text, highlighted in yellow color and flash centered.	Number of general equations of chemical reactions (or "chemical formulas") for analytic and predictive computations for similar situations.
Figures (F)	Number of Figures.	Number of Figures.
Tables (T)	Number of Tables highlighted with light blue color.	Number of Tables.

Time Allocation Points (TAP)	**Relevant Component in High School Mathematics Textbooks**		
	Algebra I (Note: The "body text" includes all Chapter pages)	**Geometry** (Note: The "body text" includes all Chapter pages)	**Trigonometry** (Note: The "body text" does not include Mathematical Review, Definition and Properties, Problem Set, Chapter Problems, and Chapter Test sections)
Concepts (C)	Number of items in the "Big Ideas" and "Key Vocabulary" in the opening page of each Chapter; and "Main Ideas" and "New Vocabulary" in the opening page of each Section.	Number of items in the Understanding and Using the Vocabulary subsection of the Study Guide and Assessment section at the end of each Chapter.	Number of items in the Glossary section (pp. 821-826).
Intermediate Equations (IE)	Numbers of items in the "Key Concept," "Concept Summary," "Algebra Lab" in each Chapter; and Pre-requisite Skills in the Student Handbook (pp. 694-716).	Number of items in the Algebra Review and Algebra or Number Theory Link (pp. 720-725).	Number of items in Definitions (in body text, in gray background), and Math Review (in the opening page of body text, in gray background).
Governing Equations (GE)	Number of items in the "Key Vocabulary" and "Key Concepts" in the Study Guide and Review section, at the end of each Chapter.	Number of Terms, formulas for Areas, Perimeters, Problem-Solving Plans, Definitions, Properties, Concept Summary, Law, Rule, Guidelines, Postulates and Theorems in boxes throughout body text, all boxed and colored beige with blue outlines.	Number of Property (in Problem Set), Property, Corollary, Equations, Formulas, or Theorems (in body text), Definition and Property (in body text), Conclusions (in body text), Techniques (in body text and Problem Sets), and Procedures or Criteria (in body text).
Figures (F)	Number of figures in Get Ready, Real World Example, Activity X, and Real World Link.	Number of illustrations in Hands-On Geometry, Investigation, Graphing Calculator Exploration, Technology Tip, Math in Workplace, InfoGraphics, PhotoGraphics, and Guided Practice.	Number of Figures and trigonometry-related pictures.
Tables (T)	Number of Tables highlighted with light blue color, information directly related to mathematics (not including those related to physics, chemistry or others.	Number of Tables.	Number of "Properties" or "Definitions" in boxes listing and comparing items and phenomena.

Table 6. Estimated Time Allocations for High School Statics & Fluid Mechanics Courses

Textbook & Time Allocation (TA) [Weeks]	**Time Allocation Points (TAP)**							**Comparative Estimation**	
	S	**C × 10**	**IE**	**GE × 10**	**F**	**T**	$\sum$TAP [Points]	$\text{ETA}_{\substack{\text{Future High School}\\ \text{Engineering Course}}} = \frac{\left(\text{TA}_{\substack{\text{Current High School}\\ \text{Math/Science Course}}}\right)\left(\sum \text{TAP}_{\substack{\text{College}\\ \text{Engineering Textbook}}}\right)}{\sum \text{TAP}_{\substack{\text{High School}\\ \text{Math/Science Textbook}}}}$ [Weeks]	
Statics (N/A)	71	66 × 10 = 660	142	103 × 10 = 1030	135	4	2042	N/A	N/A
Fluid Mechanics (N/A)	124	114 × 10 = 1140	515	161 × 10 = 1610	268	18	3675	N/A	N/A
Physics (40)	91	173 × 10 = 1730	211	116 × 10 = 1160	405	141	3738	$\text{ETA}_{\substack{\text{Future HS}\\ \text{Statics Course}}} = \frac{(40)(2042)}{3738}$ $= 22 \text{ Weeks}$	$\text{ETA}_{\substack{\text{Future HS}\\ \text{Fluid Course}}} = \frac{(40)(3675)}{3738}$ $= 39 \text{ Weeks}$
Chemistry (40)	68	306 × 10 = 3060	353	58 × 10 = 580	366	102	4529	$\text{ETA}_{\substack{\text{Future HS}\\ \text{Statics Course}}} = \frac{(40)(2042)}{4529}$ $= 18 \text{ Weeks}$	$\text{ETA}_{\substack{\text{Future HS}\\ \text{Fluid Course}}} = \frac{(40)(3675)}{4529}$ $= 32 \text{ Weeks}$
Algebra I (40)	96	264 × 10 = 2640	114	186 × 10 = 1860	318	15	5043	$\text{ETA}_{\substack{\text{Future HS}\\ \text{Statics Course}}} = \frac{(40)(2042)}{5043}$ $= 16 \text{ Weeks}$	$\text{ETA}_{\substack{\text{Future HS}\\ \text{Fluid Course}}} = \frac{(40)(3675)}{5043}$ $= 29 \text{ Weeks}$
Geometry (40)	96	307 × 10 = 3070	49	215 × 10 = 2150	347	14	5726	$\text{ETA}_{\substack{\text{Future HS}\\ \text{Statics Course}}} = \frac{(40)(2042)}{5726}$ $= 14 \text{ Weeks}$	$\text{ETA}_{\substack{\text{Future HS}\\ \text{Fluid Course}}} = \frac{(40)(3675)}{5726}$ $= 26 \text{ Weeks}$
Trigonometry (40)	110	174 × 10 = 1740	57	260 × 10 = 2600	532	0	5039	$\text{ETA}_{\substack{\text{Future HS}\\ \text{Statics Course}}} = \frac{(40)(2042)}{5039}$ $= 16 \text{ Weeks}$	$\text{ETA}_{\substack{\text{Future HS}\\ \text{Fluid Course}}} = \frac{(40)(3675)}{5039}$ $= 29 \text{ Weeks}$
For a Future High School Statics Course:	$\text{ETA}_{\substack{\text{Average}\\ \text{Future HS}\\ \text{Statics Course}}} = \frac{\sum_{i=1}^{n} \text{TA}_{\substack{\text{Future HS}\\ \text{Statics Course}}}}{n} = \frac{22+18+16+14+16}{5} = 17 \text{ Weeks}$					For a Future High School Fluid Mech. Course:	$\text{ETA}_{\substack{\text{Average}\\ \text{Future HS}\\ \text{Statics Course}}} = \frac{\sum_{i=1}^{n} \text{TA}_{\substack{\text{Future HS}\\ \text{Statics Course}}}}{n} = \frac{39+32+29+26+29}{5} = 31 \text{ Weeks}$		

Using this conceptual framework, the Estimated Time Allocation (ETA) for a future high school engineering course obtained by comparing a particular engineering course with a single mathematics or science course are averaged to obtain the Estimated Time Allocation (ETA) for a particular future engineering course. As shown in Table 6, the Estimated Time Allocation for incorporating the 9th Grade "age-possible" statics topics (Table 2A) is approximately 17 weeks; and the Estimated Time Allocation for incorporating the 9th Grade "age-possible" fluid mechanics topics (Table 2B) is approximately 31 weeks (i.e., both require less or more than one semester). These two rough estimates could be considered as relatively realistic based on the following facts: (1) in California's high schools, the physics and chemistry courses both cover basically the pre-calculus portions of related content knowledge and both take two semesters for high school students to complete; if the students did not complete them at high schools, they could take them at two-year community colleges, and in this case, they will take each of the courses in one semester; in other words, for the same amount of knowledge content, one semester of time allocation at college level could correspond to two semesters of time allocation at high school level; (2) as mentioned before, for the textbooks used in college-level statics and fluid mechanics courses, approximately 50% of volumes are based on pre-calculus mathematics skills; and the volumes of the college-level statics and fluid mechanics textbooks are approximately similar to those for high school level mathematics, physics and chemistry textbooks (all in the range of 600-800 pages); thus, the pre-calculus portions of knowledge content covered in both college level statics and fluid mechanics textbooks could require approximately one semester of time allocation at high schools for both subjects. These estimates are merely tools for planning the development of relevant curriculum; and the actual allocation of time could be determined only after the new curriculum has been developed and tried through pilot studies, which could help eliminate certain numbers of topics that are not so age-feasible or not so essential.

Conclusions and Recommendations

This article has presented (1) reference lists for high school 9th Grade "age-possible" statics and fluid mechanics topic, and for the mathematics and science pre-requisites, and (2) a conceptual framework for estimating the allocation of time for incorporating engineering topics into high school curriculum. The following are recommended: (1) Further research: I shall continue research on defining K-12 age-possible engineering knowledge content from the subjects of dynamics, strength of materials, material science, heat transfer, thermodynamics, engineering economics, aerodynamics and mechanism design, using similar methods. (2) Curriculum development: Existing K-12 engineering and technology curriculum developers could use the Tables 2A, 2B, 3A, 3B, 4A, and 4B as references for the development of new K-12 engineering instructional materials or for the incorporation of statics- and fluid mechanics-related engineering knowledge and skills into their previously developed instructional materials; (3) Pilot study: High schools could conduct pilot pedagogic experiments to determine the actual age-feasibility and age-appropriateness of all statics- and fluid mechanics-related analytic knowledge content identified in Tables 2A, 2B, 3A, 3B, 4A, and 4B; and K-12 mathematics and science teachers could use the same Tables as references to incorporate statics and fluid mechanics topics into respective curriculum.

References

Committee on K-12 Engineering Education (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: National Academy of Engineering and the National Research Council.

Hacker, M. (2011). Private email correspondence, Saturday, January 22, 2011, 4:58:44 PM.

Lewis, T. (2007). Engineering education in schools. *International Journal of Engineering Education*, 23(5), 843-852.

Locke, E. (2009a). Proposed model for a streamlined, cohesive, and optimized k-12 STEM curriculum with a focus on engineering. *The Journal of Technology* Studies. Volume XXXV, Number 2, Winter 2009. Retrieved Thursday, February 17, 2011 from http://scholar.lib.vt.edu/ejournals/JOTS/v35/v35n2/pdf/locke.pdf.

Locke, E. (2009b). *Report on the achievements of K-12 engineering education in Australia & its positive referential values for the evolution of a potentially viable K-12 engineering & technology curriculum in the United States*. Unpublished research document.

Smith, P. C., & Wicklein, R. C. (2007). *Identifying the essential aspects and related academic concepts of an engineering design curriculum in secondary technology education.* Unpublished internal research report, NCETE. Retrieved January 30, 2009 from http://ncete.org/flash/publications.php.

About the Author:

Edward Locke 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 an independent scholar on the issue of high school engineering curriculum, working in collaboration with professors of the Engineering Department, at California State University Los Angeles, and at East Los Angeles College; and he could be reached at edwardnlocke@yahoo.com.

Acknowledgement:

This is to acknowledge the assistance provided by Professor Jose Ramirez, Professor Kamyar Khashayar, and SFP Specialist Maria L. Calpito at the Engineering Department, East Los Angeles College, in securing mathematics, physics and chemistry textbooks used in local high schools, in the Greater Los Angeles Area, California; these textbooks have been used in the extraction of research data used in this article.