PART FIVE

STRATEGIES FOR IMPLEMENTING ENGINEERING ANALYTIC AND PREDICTIVE PRINCIPLES AND COMPUTATIONAL SKILLS INTO K-12 ENGINEERING CURRICULUM

Structural Incorporation of Engineering Topics into K-12 Engineering Curriculum

Similar to other engineering foundation courses, topics of statics include two components: (1) those based on pre-calculus mathematics, and (2) those based on calculus mathematics. Strategies for infusing engineering analytic and predictive principles and computational skills into K-12 engineering curriculum should vary according to the current conditions of K-12 mathematics education. In this Research Paper, the Math Course Sequence developed under Georgia Performance Standards for Mathematics shown in *Figure 3* (p. 24) is used as a reference for the exploration of strategies to infuse both components into K-12 curriculum.

Strategy for Infusing Pre-calculus Level Statics Topics

<u>Summary of Table 8 (pp. 58-80)</u>: A careful analysis of Table 8 data could lead to several important conclusions for the potential structural incorporation of substantial amount of statics-related engineering analytic and predictive principles and computational skills into a viable future K-12 engineering curriculum.

<u>Findings on high school appropriate statics topics</u>: Out of all 10 Chapters in the selected college-level statics textbook (Beer et al, 2004), 5 whole chapters are found to be appropriate for Grade 9 students, although some special mathematics skills (such as

additions and subtractions of vectors), should be explored during the course; these "special mathematics" are appropriate for 9th Grade students to learn, based on their mandated mastery of pre-requisite mathematics concepts and skills prior to 8th Grade, although they are assigned to grade level higher than 9th Grade by Georgia Performance Standards for Mathematics. For example, "vector graphics" pedagogically could be taught at 9th Grade, but is assigned to 11th Grade; another example is the Six Trigonometry Functions, i.e., sine, cosine, tangent, cotangent, secant and cosecant for right triangles, which could be taught as 9th Grade, but are assigned to 10th Grade as part of the Mathematics Course Sequence under Options 2 and 3.

Difference between Mathematics and Engineering: In mathematics courses, strict adherence to pre-requisite sequence is very important; on the other hand, in engineering, specifically selected mathematics skills could be explored in order to carry out formula-based computations; thus, they could be treated independently and out of the normal mathematics learning sequence, without damaging the integrity of the learning process. In Table 8 (pp. 58-80), these "special mathematics" are marked with a notation of "→ To be taught as a special math topic" and typed in red. The above-mentioned 5 whole chapters could constitute the statics portion of a high school appropriate Statics and Dynamics course for 9th Grade students, as shown in *Figure 4D* (p. 49). Implementing these engineering analytic and predictive knowledge content at high school level would (1) help high school graduates streamline into undergraduate engineering programs; and (2) increase efficiency of university instructors' teaching tasks. The 5 chapters and their respective needs for "special mathematics topics" instruction are explained as follows:

- <u>Chapter 1 (Introduction)</u>: Addition and subtraction of force vectors are to be taught as a special mathematics topic;
- <u>Chapter 2 (Statics of Particles)</u>: The Six Trigonometric Functions are to be taught as a special mathematics topic; for Section 2.15 (Equilibrium of a Particle in Space), specific skills in linear algebra could be taught as a special mathematics topic, if desired (however, using linear algebra in section 2.15 is NOT a part of the selected textbook, but an extra-credit skill taught by some college instructors).
- <u>Chapter 3 (Rigid Bodies - Equivalent Systems of Forces)</u>: The Six Trigonometric Functions, vector product (also called "cross product"), and scalar product (also called "dot product"), are to be taught as special mathematics topics; in addition, for Section 3.5 (Vector Products Expressed in Terms of Rectangular Components), Section 3.6 (Moment of a Force about a Point), Section 3.8 (Rectangular Components of the Moment of a Force), Section 3.10 (Mixed Triple Product of Three Vectors) and Section 3.11 (Moment of a Force about a Given Axis), specific skills in linear algebra related to vector product and scalar product need to be explored; furthermore, summation or $\sum$ notation should be explained.
- <u>Chapter 4 (Equilibrium of Rigid Bodies)</u>: Summation or $\sum$ notation should be taught as a special mathematics topic.
- <u>Chapter 6 (Analysis of Structures)</u>: The Six Trigonometric Functions are to be taught as a special mathematics topic.

Important statistics: The above 5 Chapters cover 286 pages out of 600 pages, or 48% of the selected textbook's volume (Beer et al, 2004). This practically means that close to half of the topics in a typical undergraduate statics course can be taught at high school level (Grade 9).

The proposed strategy: The statics topics covered in the above 5 chapters could be used to develop the statics portion of a 9th Grade level high school statics and dynamics course, for both their engineering analytic and predictive principles and computational skills based on pre-calculus mathematics. Prior to 9th Grade, some general knowledge associated with these topics could be incorporated into general science study, as an introduction to engineering foundation.

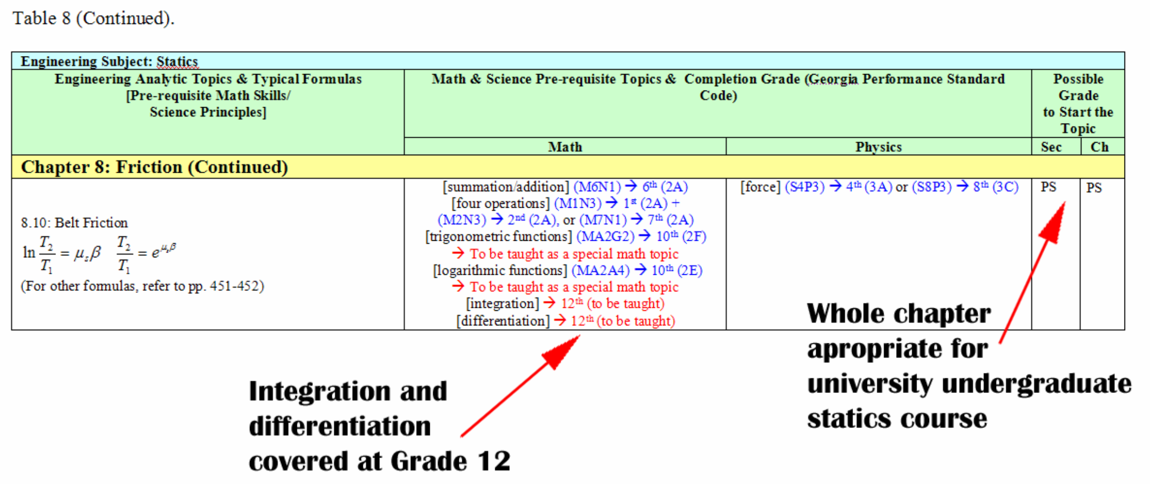


Table 8 (Continued).

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 8: Friction (Continued)				
8.10: Belt Friction $\ln \frac{T_2}{T_1} = \mu_s \beta \quad \frac{T_2}{T_1} = e^{\mu_s \beta}$ (For other formulas, refer to pp. 451-452)	[summation/addition] (M6N1) → 6th (2A) [four operations] (M1N3) → 1st (2A) + (M2N3) → 2nd (2A), or (M7N1) → 7th (2A) [trigonometric functions] (MA2G2) → 10th (2F) → To be taught as a special math topic [logarithmic functions] (MA2A4) → 10th (2E) → To be taught as a special math topic [integration] → 12th (to be taught) [differentiation] → 12th (to be taught)	[force] (S4P3) → 4th (3A) or (S8P3) → 8th (3C)	PS	PS

Whole chapter apropriate for university undergraduate statics course

Integration and differentiation covered at Grade 12

Figure 6. Notation for undergraduate level appropriate statics topics.

Strategy for Infusing Beginning Calculus Level Statics Topics

Statics topics that are more appropriate for an undergraduate statics course: The following chapters in the selected textbook (Beer et al, 2004) all involve substantial application of beginning calculus (integration and differentiation) and functions (such as logarithmic), which are beyond 9th Grade students' mastery of mathematics skills, as mandated by Georgia Performance Standards for Mathematics and featured in the Math Course Sequence established by Georgia Department of Education for Secondary Mathematics (Grades 6-12), as shown in *Figure 3* (p. 25):

- Chapter 5 (Distributed Forces: Centroids and Centers of Gravity): Sigma notation, and integration;
- Chapter 7 (Forces in Beams and Cables): Integration;
- Chapter 8 (Friction): Integration, and logarithmic function;
- Chapter 9 (Distributed Forces - Moments of Inertia): Integration, partial derivatives and gradient; and
- Chapter 10 (Method of Virtual Work): Integration, derivatives, partial derivatives (1st and 2nd degrees).

Under the Math Course Sequence developed by Georgia Department of Education, beginning calculus is learned at Grade 12; thus, on table 8, the pre-requisites of integration and differentiation are marked with the notation "→ 12th (to be taught)" in red; and the code "PS" (post-secondary) is entered in the "Ch" sub-column of "Possible Grade to Start the Topic" column, as shown in *Figure 6*. Skipping Chapter 5 (Distributed Forces - Centroids and Centers of Gravity) will not affect the smooth transition from Chapter 4 topics to Chapter 6 topics. In fact, Chapter 6 topics (Analysis of Structure) have been implemented as a standalone topic in K-12 curriculum as a popular theme of science, such as in West Point Bridge Design Contest (http://bridgecontest.usma.edu/). Therefore, from a conservative pedagogic perspective, topics of statics covered in Chapters 5, 7, 8, 9 and 10 should be reserved for post-secondary engineering undergraduate programs.

The extent of calculus skills used in undergraduate engineering foundation courses: A typical university level undergraduate engineering program usually requires three calculus courses plus one differential equation course as a mathematic foundation for engineering and physics courses. These calculus courses are usually the same as those required of students majored in mathematics and are aimed at building a comprehensive calculus skill set. In most of engineering foundation courses, however, the calculus-based computational skill set is rather very limited. This point could be illustrated by the computational formulas listed in Table 8 (pp. 58-80), in the portions that cover Chapters 5 (pp. 66-68), 7 (pp. 69-70), 8 (pp. 71-72), 9 (pp. 73-77) and 10 (pp. 78-80). This is equally true for most engineering analytic principles and computational formulas found in many other textbooks used for dynamics, fluid mechanics, strength of materials, and others. In fact, across all textbooks used in these undergraduate engineering foundation courses, the required calculus skill set is usually limited to the following: (1) integrals (single and multiple); (2) derivatives (including partial derivatives, second-degree partial derivatives, and gradient); (3) analytic geometry (polar coordinates and rectangular coordinates); (4) vectors (dot product and cross product); and (5) sigma notation.

General applications of calculus in science and engineering: Calculus includes two major parts, i.e., integration and differentiation. For the definite integrals, which constitutes a fairly large portion of calculus skills set used in undergraduate foundation engineering courses, *Calculus Early Transcendentals 8th Edition* by Howard Anton, Irl Bivens and Stephen Davis (published by John Wiley & Sons, Inc., 2005, ISBN No. 0-471-47244-1), a popular college level textbook four all three required calculus courses in typical science and engineering programs, devotes 1 out of 16 chapters (Chapter 7 -

Applications of the Definite Integral in Geometry, Science and Engineering, pp. 442-509), to the applications of this important portion of calculus in science and engineering. This chapter covers the following sections: (7.1) Area Between Two Curves; (7.2) Volumes by Slicing Disks and Washers; (7.3) Volumes by Cylindrical Shells; (7.4) Length of a Plane Curve; (7.5) Area of a Surface of Revolution; (7.6) Average Values of a Function and its Applications; (7.7) Work; (7.8) Fluid Pressure and Force; and (7.9) Hyperbolic Functions and Hanging Cables. These topics, plus partial derivatives and multiple integrals, are the needed calculus skill set for typical engineering students in undergraduate lower-division courses, as well as in most of the practical engineering design on a daily basis.

Possibility for “highly-talented” students: Although the statics-related engineering analytic and predictive principles and skills covered in Chapters 5, 7, 8, 9 and 10 of the selected textbook (Beer et al, 2004) involve some basic calculus (mainly, integration and differentiation) and logarithmic functions, they could still be infused into high school engineering curriculum and taught to mathematically “highly talented” students enrolled in Option 5 of the Math Course Sequence (*Figure 3*, p. 24), as extra learning materials, provided that relevant beginning calculus and logarithmic concepts and computational skills are covered at the start of the topics. However, for “average” students, these topics might be better reserved for a post-secondary course.

The proposed strategy for “average” students: In the Math Course Sequence developed under Georgia Performance Standards for Mathematics (*Figure 3*, p. 24), calculus is taught after 9th Grade (at 11th Grade for mathematically “highly-talented” students enrolled in Option 5, and at 12th Grade for all other students enrolled in Options

1, 2, 3, and 4). Therefore, if the most important calculus-based engineering analytic and predictive course contents are to be considered for high school instruction, then special strategies must be used to overcome the calculus barrier. The following two approaches are proposed for consideration and illustrated in *Figure 7*:

1. The special calculus training session approach: Instead of waiting for "average" high school students to complete two full calculus courses before proceeding to the study of beginning-calculus based engineering topics, it would be possible to develop some short-term training sessions to allow average 9th Grade students to master particular set of calculus computational skills relevant to engineering topics. Application: This approach is designed for high school level engineering subjects that have a rather smaller portion of pre-calculus based topics, but a fairly large portion of early calculus based ones, such as dynamics. Potential advantages: This approach will allow students to explore the most important calculus-based engineering analytic principles and computational skills starting at 9th Grade, while learning the most basic skills in calculus (such as integration and differentiation) before they "formally" enroll in an AP (Advanced Placement) Calculus course; adopting this approach could (1) make study of calculus more "real-world" and attractive, and (2) smooth the transition from trigonometry-based science instruction at K-12 level to calculus-based science and engineering education at college level. Scholarly advice: I have discussed this approach with Dr. Sidney Thompson, Professor of Engineering at Driftmier Engineering Center, the University of Georgia; he indicated that as long as high school engineering

and technology teachers teach special calculus topics in an “application” way that does not get into conflict with the “theoretical way” high school mathematics teachers teach them, it would be possible to do it (advisory meeting, June 11, 2009).

2. The integrative STEM approach: Students at 9th, 10th and 11th Grades could concentrate on studying high school appropriate pre-calculus portion of engineering foundation topics; this alone could still help them to better prepare for college majors in engineering than what is offered under the current program. In addition, using the integrative STEM approach within the framework of Project-Based Learning (PBL), they could explore the most important ones among the early-calculus based engineering analytic and predictive principles and computational skills at 12th Grade, as part of the AP (Advanced Placement) Calculus course. Application: This approach would work better for those engineering subjects with smaller portion of calculus-based topics, such as statics and strength of materials. Potential advantages: The advantages of integrative STEM approach to calculus-based science and engineering education might include (1) making calculus instruction less boring and more attractive to high school students; (2) fostering real-world problem analysis and problem-solving skills; and (3) contributing to training more innovative engineering talent for the future by attracting more high school students to engineering careers. Scholarly advice: Dr. Sidney Thompson indicated that this method would work; and that he had no preference for either approach (advisory meeting, June 11, 2009).

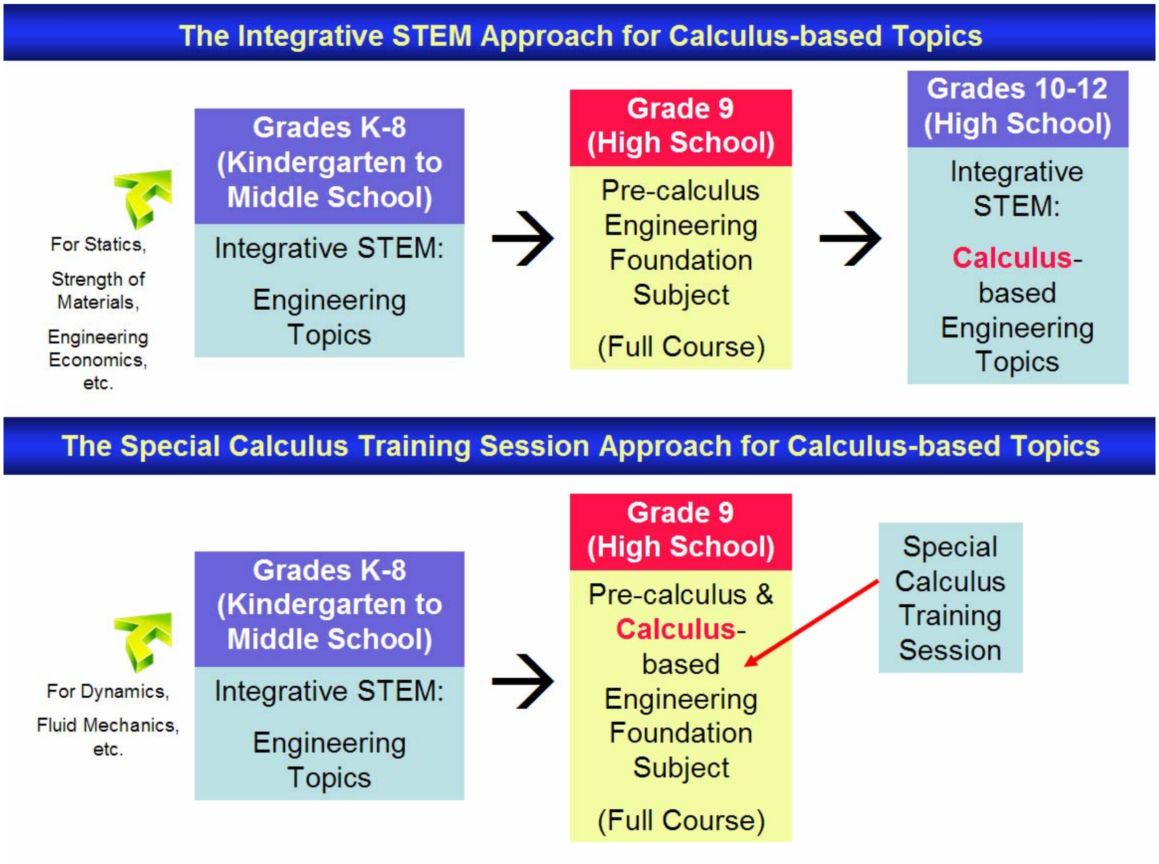


Figure 7. *Two different approaches for infusing engineering analytic course content into K-12 engineering curriculum*

Selecting the Most Important Engineering Analytic and Predictive Principles and Formulas for K-12 Engineering Curriculum

A Proposed Five-Point Likert Scale Survey Study

Planned five-point Likert Scale survey study: Based on data available from Table 8 (pp. 58-80), statics-related engineering analytic principles and computational skills covered in the selected statics textbook (Beer et al, 2004) have been divided and tabulated into two five-point Likert Scale Delphi survey forms:

- Table 9 (Delphi - Likert Scale Questionnaire on the Importance of Various Statics Topics Selected for High School Engineering Curriculum For The Pre-calculus Portion): Statics-related analytic principles and formulas covered in Chapters 1, 2, 3, 4, and 6 of the selected textbook (Beer et al, 2004) are listed in Table 9 (pp. 81-89), which constitute a survey instrument for determining the relative importance of various pre-calculus-based topics of statics to be included into a potentially viable K-12 engineering curriculum.
- Table 10 (Delphi - Likert Scale Questionnaire on the Importance of Various Statics Topics Selected for High School Engineering Curriculum For the Calculus Portion): Statics analytic principles and formulas covered in Chapters 5, 7, 8, 9 and 10 of the selected textbook (Beer et al, 2004) are listed in Table 9 (pp. 89-101), which constitute a survey instrument for determining the relative importance of various beginning calculus-based topics of statics to be included into a potentially viable K-12 engineering curriculum.

Reasons for establishing the order of importance for various statics topics: Since the K-12 curriculum is already crowded with many mandated subjects, it is unrealistic to expect that all topics of engineering analytic and predictive principles and computational skills that are pedagogically appropriate for K-12 students could be included in any potentially viable K-12 engineering curriculum. Instead, we should collect expert opinions of the relative importance of various topics, through a 5-point Likert survey study. This survey study could be used to (1) determine the relative importance of various engineering analytic principles and computational skills for inclusion into a potentially viable K-12 engineering curriculum; and (2) eventually establish a set of national or state K-12 engineering performance standards.

The five-point Likert Scale used in Table 9 is shown and explained below.

Likert Scale (Score of the Order of Importance) for Engineering Analysis Topics				
Totally Unimportant	Not So Important	Might Be Important	Important	Very Important
1	2	3	4	5

<u>Review, validation, and approval of Tables 8, 9 and 10</u>: Table 8 (Engineering Topics Mathematics and Science Pre-requisite Completion Chart for the Subject of Statics), Table 9 (Delphi - Likert Scale Questionnaire on the Importance of Various Statics Topics Selected for High School Engineering Curriculum For The Pre-calculus Portion), and Table 10 (Delphi - Likert Scale Questionnaire on the Importance of Various Statics Topics Selected for High School Engineering Curriculum For The Calculus Portion) will be submitted to University of Georgia engineering professors, Dr. Robert Wicklein, Dr. John Mativo and Dr. Sidney Thompson, for review and validation of the determination of the appropriateness of various topics of statics to be included into a potentially viable K-12 engineering curriculum (mainly at Grade 9), in terms of their respective fulfillment of mathematics and physics pre-requisites at various grade levels, as mandated by Georgia Performance Standards. These University of Georgia professors respectively possess abundant experience teaching both K-12 and university students engineering design and technology, great expertise in making judgment on the feasibility of infusing specific engineering knowledge content into K-12 curriculum, and solid knowledge on the subject of statics. Upon completion of such review and validation, necessary changes will be made to Tables 8, 9 and 10 in order to eliminate any possible

technical errors or potential shortcomings due to lack of considerations for any particular pedagogic and academic conditions in the current K-12 system in the United States (particularly, in the State of Georgia). Upon completion of these necessary changes and the final approval by the above three University of Georgia professors, Tables 9 and 10 will be technically ready to be used as a five-point Likert Scale survey instrument. Next, Tables 9 and 10 will be submitted to NCETE leader Dr. Kurt Becker at Utah State University as well as other appropriate authorities for a final approval.

Delphi survey with participants: Next, Tables 9 and 10 survey forms will be presented to the following five groups of stakeholders in K-12 engineering and technology curriculum, who are considered experts in the field of engineering and technology education:

- Group 1 (University Engineering and Technology Faculty): To be selected among professors and Ph.D fellows in the universities participating in the National Center for Engineering and Technology Education program (i.e., University of Georgia, Utah State University, California State University Los Angeles, University of Minnesota, University of Illinois Urbana-Champaign, Brigham Young University, Illinois State University, North Carolina A&T University, and University of Wisconsin Stout.), as well as from important institutions of engineering education, such as Georgia Institute of Technology, Massachusetts Institute of Technology, California Institute of Technology, Virginia Institute of Technology, and members of engineering education related professional organizations, such as American Society for Engineering Education;

- Group 2 (University K-12 Engineering and Technology Education Faculty): To be selected among professors and Ph.D fellows in the universities participating in the above-listed National Center for Engineering and Technology Education program;
- Group 3 (University Undergraduate Senior-Year Engineering Students): To be selected randomly among senior-year undergraduate engineering students at the College of Agricultural and Environmental Sciences, the University of Georgia, from the Mechanism, Civil, Electrical and other majors, at least 2 students per major, for a total of up to 10 student participants;
- Group 4 (K-12 technology and STEM Teachers and Administrators): To be selected among K-12 schools in Georgia, as well as California, Utah and other states if possible;
- Group 5 (Practicing Engineers and Technicians): To be selected among members of relevant professional associations, such as American Society of Mechanical Engineers, American Society of Civil Engineers and others.

Lists of the above-mentioned five Groups of Participants will be created based on pre-established selection criteria, which is beyond the scope of this paper.

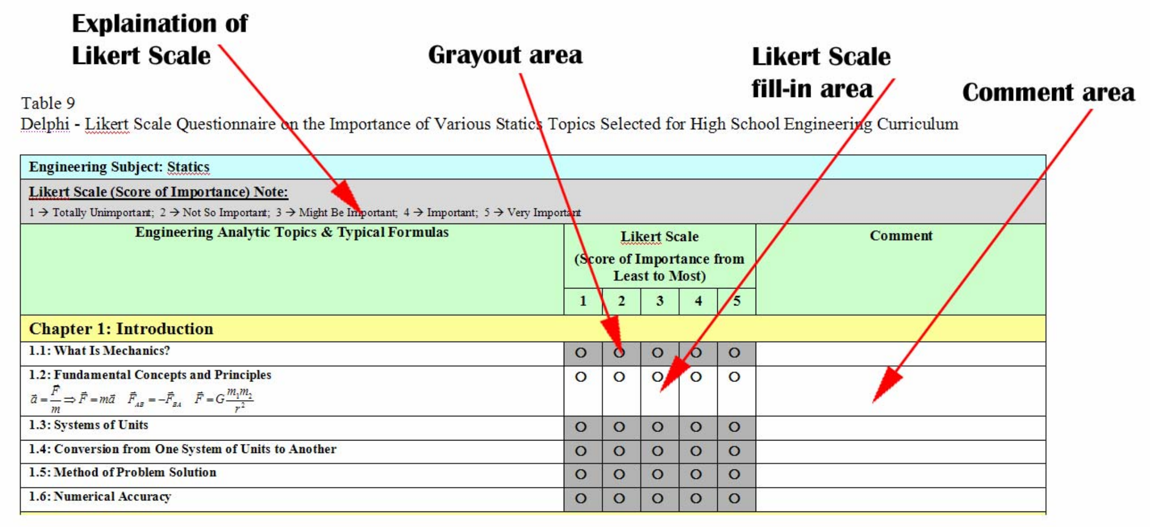


Table 9

Delphi - Likert Scale Questionnaire on the Importance of Various Statics Topics Selected for High School Engineering Curriculum

Engineering Subject: Statics						
Likert Scale (Score of Importance) Note: 1 → Totally Unimportant; 2 → Not So Important; 3 → Might Be Important; 4 → Important; 5 → Very Important						
Engineering Analytic Topics & Typical Formulas	**Likert Scale (Score of Importance from Least to Most)**					**Comment**
	1	**2**	**3**	**4**	**5**	
Chapter 1: Introduction						
1.1: What Is Mechanics?	○	○	○	○	○	
1.2: Fundamental Concepts and Principles $\vec{a}=\frac{\vec{F}}{m}\Rightarrow\vec{F}=m\vec{a}$ $\vec{F}_{AB}=-\vec{F}_{BA}$ $\vec{F}=G\frac{m_1m_2}{r^2}$	○	○	○	○	○	
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	○	○	○	○	○	

Figure 8. Table 9 survey form.

<u>Completion and statistic analysis of Tables 9 and 10 survey forms</u>: As shown in *Figure 8*, there are topics of statics covered in sections of the selected textbook (Beer et al, 2004), which absolutely need to be included in any potentially viable high school appropriate statics course, in order to maintain the integrity of instructional sequence or to provide students with needed background information; this type of topics should be included anyway regardless of their perceived importance based on expert opinion. For this type of topics, the five-point Likert Scale space is grayed out. The survey participants will be asked to fill in one scale per item and to offer additional comments in the Comment column. Upon collection of all survey forms, statistic analysis will be made on Likert Scale data to compute the means of scores of importance for each topic of statics. Comments will be analyzed and used for additional rounds of Likert Scale Delphi survey. The final results will be tabulated into a list of all topics of statics on the basis of their perceived importance; and such list will be used as a reference for potential development of (1) high school appropriate statics course, and (2) potential national and state performance standards for K-12 engineering curriculum.

Basic question for the survey: The survey (Tables 9 and 10) will be addressing the question of the importance of particular statics topics, from the different perspectives of different groups of practitioners in engineering design and education, based on previously discussed five-point Likert Scale.

Developing Appropriate Pedagogic Strategy for K-12 Engineering Curriculum

Differences between High School and College Students and Pedagogic Strategy for K-12 Engineering Curriculum

It appears to be self-evident that substantial differences exist between high school students and college undergraduate students, and therefore, in order to develop the analytic and predictive abilities of high school students enrolled in engineering pathways, appropriate pedagogic strategy must be developed and improved. Compared to college students, high school students usually have lower degree of cognitive maturity and less ability to understand complicated and abstract scientific concepts, and therefore, the following might be necessary for successful instruction of engineering analytic principles:

- Using plain English to explain abstract engineering principles with everyday analogy and concrete examples;
- Using videos, prototypes, and other physical and visual artifacts to demonstrate how engineering analytic principles work;

- Showing the interconnection among various types of engineering analytic principles, and comparing the similarities and differences among them (with concept maps, formulas sheets, etc.);
- Providing high school students with well-organized instructional materials appropriate to their age.

Modernization of Engineering Pedagogy

Project-Based Learning (PBL): This pedagogic model has been widely reported as a successful instrument for improving K-12 mathematics and science education. Previous experience by Sirinterlikci and Mativo (2005) indicated that secondary school students could handle engineering design activities in an inter-disciplinary setting, using a Project-Based Learning model. Sirinterlikci and Mativo's pedagogic experiment indicated that learning engineering design help high school students to increase interests in STEM and academic success (*Figure 9*).

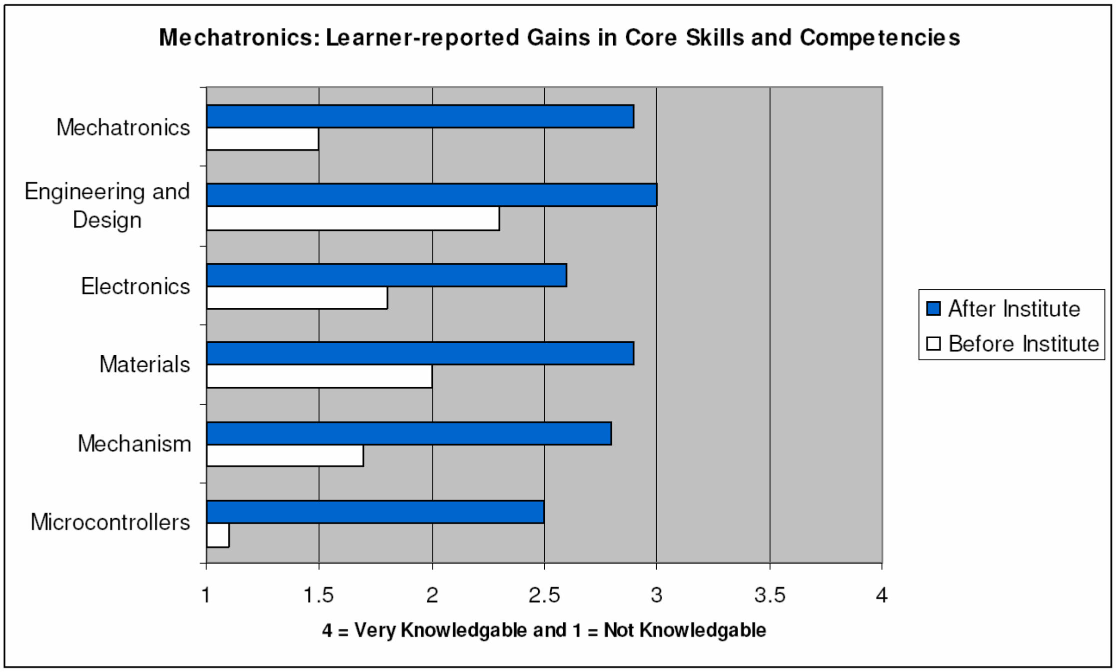


Figure 9. Project-Base Learning improves high school students core STEM skills.

Important Considerations to be Taken

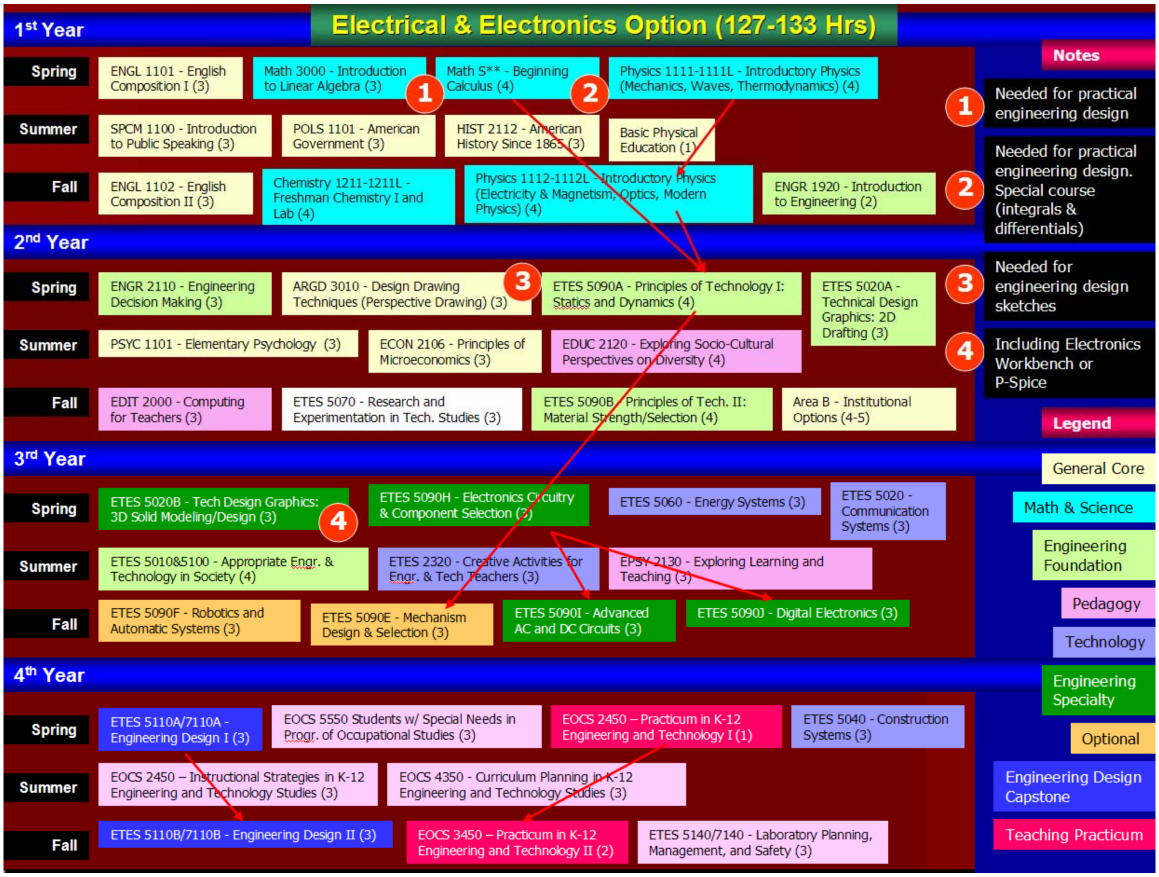
Means and ends: The aim of infusing engineering analytic and predictive principles and computational skills into a potentially viable K-12 engineering curriculum is NOT to make students instruments of computations, but to foster their real ability in innovative engineering design that is based on solid mastery of necessary analytic tools that will allow them to use generic engineering design approach to create real-world quality products and systems, which are appropriate to their age. From the perspective of pedagogic philosophy, this approach is inspired by the idea of "a unified curriculum framework for technology education" explore by Rojewski and Wicklein (1999).

Focus on problem-solving: The aim of this Research Paper is NOT to encourage rote memorization of engineering analytic principles and computational formulas, or their applications in solving a few simple homework problems in the "analytic reduction" model (although this is a necessary task), but to foster the real ability of solving real-world problems, which involve related engineering analytic principles and of course, computational formulas, from various subjects, in a "system thinking" model.

Understanding the nature of engineering: Engineering is essentially applied science; thus, what is needed is NOT to turn high school students into well-programmed testing robots, but to train them into potentially creative designers of innovative products and systems, who (1) understand the essentials of engineering design process; (2) possess solid mastery of the basic analytic and predictive principles and skills covered in the K-12 engineering curriculum; and (3) know how to independently explore new topics beyond those covered in the standard curriculum, to learn on their own and to locate knowledge and information. Therefore, Project-Based Learning would be a good model for systematically deliver well-organized and cohesively-related sets of engineering analytic principles and skills to high school students.

<u>Three-Method Approach</u>: Digital revolution has brought tremendous changes to engineering education and practice, while traditional learning methods still apply. Using different methods to learn engineering analytic principles and skills would help consolidate the mastery of knowledge and skills. Under the general model of Project-Base Learning, three methods could be integrated in the instruction of engineering analytic principles and skills:

1. <u>Traditional analysis and computations using formulas</u>: This creates the essential knowledge base, and is traditionally a major component of STEM instruction.
2. <u>Physical laboratory experiment</u>: This helps understanding theoretical constructs through hands-on experience, and is traditionally a major component of STEM instruction.
3. <u>Digital simulation</u>: This is a must-have essential skill in today’s real-world engineering practice, and this area of STEM instruction should be strengthened so as to better prepare students for future engineering careers.



Electrical & Electronics Option (127-133 Hrs)

1st Year

Spring
- ENGL 1101 - English Composition I (3)
- Math 3000 - Introduction to Linear Algebra (3) ①
- Math S** - Beginning Calculus (4) ②
- Physics 1111-1111L - Introductory Physics (Mechanics, Waves, Thermodynamics) (4)

Summer
- SPCM 1100 - Introduction to Public Speaking (3)
- POLS 1101 - American Government (3)
- HIST 2112 - American History Since 1865 (3)
- Basic Physical Education (1)

Fall
- ENGL 1102 - English Composition II (3)
- Chemistry 1211-1211L - Freshman Chemistry I and Lab (4)
- Physics 1112-1112L - Introductory Physics (Electricity & Magnetism, Optics, Modern Physics) (4)
- ENGR 1920 - Introduction to Engineering (2)

2nd Year

Spring
- ENGR 2110 - Engineering Decision Making (3)
- ARGD 3010 - Design Drawing Techniques (Perspective Drawing) (3) ③
- ETES 5090A - Principles of Technology I: Statics and Dynamics (4)
- ETES 5020A - Technical Design Graphics: 2D Drafting (3)

Summer
- PSYC 1101 - Elementary Psychology (3)
- ECON 2106 - Principles of Microeconomics (3)
- EDUC 2120 - Exploring Socio-Cultural Perspectives on Diversity (4)

Fall
- EDIT 2000 - Computing for Teachers (3)
- ETES 5070 - Research and Experimentation in Tech. Studies (3)
- ETES 5090B - Principles of Tech. II: Material Strength/Selection (4)
- Area B - Institutional Options (4-5)

3rd Year

Spring
- ETES 5020B - Tech Design Graphics: 3D Solid Modeling/Design (3) ④
- ETES 5090H - Electronics Circuitry & Component Selection (3)
- ETES 5060 - Energy Systems (3)
- ETES 5020 - Communication Systems (3)

Summer
- ETES 5010&5100 - Appropriate Engr. & Technology in Society (4)
- ETES 2320 - Creative Activities for Engr. & Tech Teachers (3)
- EPSY 2130 - Exploring Learning and Teaching (3)

Fall
- ETES 5090F - Robotics and Automatic Systems (3)
- ETES 5090E - Mechanism Design & Selection (3)
- ETES 5090I - Advanced AC and DC Circuits (3)
- ETES 5090J - Digital Electronics (3)

4th Year

Spring
- ETES 5110A/7110A - Engineering Design I (3)
- EOCS 5550 Students w/ Special Needs in Progr. of Occupational Studies (3)
- EOCS 2450 – Practicum in K-12 Engineering and Technology I (1)
- ETES 5040 - Construction Systems (3)

Summer
- EOCS 2450 – Instructional Strategies in K-12 Engineering and Technology Studies (3)
- EOCS 4350 - Curriculum Planning in K-12 Engineering and Technology Studies (3)

Fall
- ETES 5110B/7110B - Engineering Design II (3)
- EOCS 3450 – Practicum in K-12 Engineering and Technology II (2)
- ETES 5140/7140 - Laboratory Planning, Management, and Safety (3)

Notes

① Needed for practical engineering design

② Needed for practical engineering design. Special course (integrals & differentials)

③ Needed for engineering design sketches

④ Including Electronics Workbench or P-Spice

Legend
- General Core
- Math & Science
- Engineering Foundation
- Pedagogy
- Technology
- Engineering Specialty
- Optional
- Engineering Design Capstone
- Teaching Practicum

Figure 10. The Academic Flow Chart for the Electrical and Electronics Option of my previously presented Proposed Model for K-12 Engineering and Technology Teacher Education program.

PART SIX

STRATEGIC VISION FOR ENGINEERING-ORIENTED PROFESSIONAL DEVELOPMENT

Vision for an Up to Beginning Calculus-Level K-12 Engineering & Technology Teachers' Professional Development

The Vision statement: In my opinion, "future K-12 engineering and technology teacher education programs should be based on hard core engineering design incorporating (1) general technological literacy; (2) full sets of specific engineering analysis and prediction skills from well-connected courses; and (3) generic engineering design process, which are based on up to beginning calculus level mathematics and science foundations (physics and chemistry), and which could enable future K-12 engineering and technology educators to optimize high school students' engineering analytic skills and design ability; and is realistic and pragmatic in terms of matching K-12 students cognitive maturity levels incrementally, with strictly-defined differentiation of engineering design stages, plus flexible incorporation of all positive contributions from existing programs such as Project Lead The Way."

Philosophical foundation of the vision: My Proposed Model reflects the American tradition of "Continuity + Change," based on the philosophies of utilitarianism, pragmatism and positivism, with deep respect for the time-proven engineering curricular development and pedagogic traditions. This vision has been demonstrated by my previously presented Proposed Model for Infusing Engineering design into K-12 Curriculum (Appendix 1), which has received positive encouragement from University of

Georgia engineering and technology education professors (Drs. Robert Wicklein, John Mativo, Sidney Thompson and David Gattie).

As shown in *Figures 1A*, *1B* (pp. 4-5) and *Figure 10* above, my vision for engineering-oriented professional development for future K-12 engineering and technology educators, called "B.S. in K-12 Engineering and Technology Teacher Education Program," has been formulated with sufficient details, down to the level of Academic Flow Charts for a four-year B.S. degree program with Options in Mechanical Design, Manufacturing, and Electrical & Electronics. This vision calls for (1) substantial inclusion of up to beginning calculus level of engineering analytic principles and skills grouped into engineering foundation course; (2) well-organized and cohesively-related "Option" courses which correspond to major courses in any typical undergraduate engineering program; (3) two multidisciplinary "capstone" senior design courses similar to typical "senior year design" course under typical undergraduate engineering programs; (4) engineering specific K-12 pedagogic training courses; and (5) full set of college-level mathematics and science courses, including beginning calculus, linear algebra, physics (all topics from mechanical forces to optics, based on trigonometry, but could be changed to beginning calculus-based depending on curricular administrative arrangement or academic "politics"), and chemistry.

<u>The advantages of the vision</u>: This vision is essentially aimed at training a new generation of K-12 engineering educators who can also play the role of practical engineers for industry, through an applied engineering program (or a "light version" of traditional engineering program). This vision is designed for training amphibious STEM talent with the abilities to (1) practice real-world engineering design and (2) teach

engineering design to K-12 students. The professional development in this vision would likely satisfy the needs for future K-12 engineering and technology educators to receive comprehensive and systematic, logically structured and cohesively coordinated professional development, in both areas of engineering and technology, within the framework of four-year Bachelor of Science programs, instead of being offered sporadic short-term training sessions focused on technology alone under the currently dominant model of professional development. Thus, it is a long-term vision aiming at strategic solution of America's chronic shortage in engineering graduates, not a short-term cosmetic change to the status quo.

Technical Details of the Vision

Different teacher professional development models: Custer (2007) identified five major models of professional training have been developed and used over the past half-century: (1) Curriculum-driven training; (2) Process-based; (3) Acculturation; (4) Graduate degree and (5) In-service; and indicated that the curriculum-driven models offers the most promise for encouraging additional engineering content and process in grades K-12; that it has enjoyed success for the past ten years; and that projects such a Project-Lead the Way and Modular Technology Education have proven that this approach which focus heavily on engineering concepts is effective in improving teachers' knowledge, professional performance and attitude.

In my opinion, any model to be potentially developed will work as long as it is strictly structured to the high standards established by educational authorities, coherent and systemic; and as long as both conceptual and procedural knowledge are covered (although in general, my preference is to focus on conceptual knowledge). Professional development models must be coherent and conducted on a long-term basis. Burghardt and Hacker (p. 4, 2005) identified three essential elements for STEM professional development: (1) guided lesson plan design, implementation, feedback, and revision; (2) academic year implementation; and (3) peer review and learning communities. “It has become common knowledge that the ‘one-shot’ workshop is not an effective approach for teacher learning. Professional development that is sustained over time is more closely linked to improved student learning than short term, one time experiences (Birman, Desimone, Porter, & Garet, 2000, p. 3).

A practical balance between “process-oriented engineering skills” and “core engineering concepts”: In product design, “form follows function;” analogically transposing this principle onto engineering oriented high school teachers’ professional development, the “form” is the “process-oriented engineering skills,” while “function” is “core engineering concepts”. In mathematics and science professional development, teachers must complete a full set of relevant courses, not just a few sporadic and disconnected training sessions. Mastery of the “core engineering concepts” allows future high school engineering and technology teachers to possess sufficient subject-specific knowledge to teach students, and demands great amount of pre-service training time; mastery of “process-oriented engineering skills,” on the other hand, requires years of practice in classroom teaching, generally can not be achieved within a short period of training that lasts 2 weeks or even 2 or more semester-long courses in undergraduate teacher preparatory programs. Mastery of enough content knowledge or core principles is very important in the successful implementation of educational programs. Without content knowledge, pedagogic process is meaningless. Content knowledge is like the wine while pedagogic process (a lesson plan, assessment method checklist, homework handout and assessment rubric, etc.) is like the bottle that is used to store wine and prevent it from getting lost. Both form a dialectic and symbiotic relationship. Burghardt and Hacker (n.d., p. 4) also concluded that "an important consideration in the design of the lesson plan is that science, engineering, and technology teachers are responsible for teaching and their students are responsible for learning mathematics concepts. This is a non-trivial consideration and one that requires support of the science, engineering, and technology teachers in terms of math content and pedagogy." This is very true. Math is used in the construction of computational formulas for every branch of science and engineering; thus, relevant mathematics-based computational formulas should be covered along with engineering analytic and predictive principles.

Teachers need to first master enough core concepts in order to translate them into effective teaching. To illustrate this point, Mundry (n.d., p. 3) identified some "good professional development programs" which provide teachers with experiences over time that are designed to do all of the following: (1) build knowledge (e.g., engaging in science investigations as learners, using science trade books in a study group, partnerships with scientists); (2) translate knowledge into practice (e.g., lesson design, examining classroom cases, learning misconceptions students have about content); (3) practice teaching (e.g., demonstration lessons, coaching from experienced teacher); and (4) reflect on practice (e.g., examine student work, observe videotapes of lessons). This is a workable sequence that generations of teachers have been using.

<u>A needed focus on structural coherence of professional development for future K-12 engineering and technology teachers</u>: Garet et al (2001, p. 927) indicated that one of

the core features of professional development "concerns the extent to which professional development activities are perceived by teachers to be a part of a coherent program of teacher learning. Professional development for teachers is frequently criticized on the ground that the activities are disconnected from one another - in other words, individual activities do not form part of a coherent program of teacher learning and development." In my opinion which falls in line with Caret et al's argument, simply adding a few topics of engineering design using commercial or non-profit programs would not fundamentally improve engineering education in the United States. Neither old-fashioned "general technological literacy," nor its cosmetic remodeling as a "pre-engineering pipeline" which in practical terms, means strengthening K-12 mathematics and science with very limited inclusion of engineering design project, will address United States' need for innovative engineers and scientists in the 21st Century of Globalization. Switching to a hard core K-12 engineering and technology curriculum could be regarded as necessary. However, under this new paradigm, existing programs such as Project Lead The Way will continue to operate even to a greater scope, although necessary changes at technical level might need to be explored.

Personnel or recruitment issues: In my opinion, the focus of engineering professional development should be placed on education, recruitment and development of engineering and technology education teachers, with a fundamentally reformed program, rather than being satisfied with a half or even quarter measure of sporadic "engineering design training session" of technology teachers, or relying on part-time employment of practicing or retired engineers in K-12 classrooms (these are unfortunately practiced up to this day. They sound "economical" in pure financial sense, but so far did not lead to substantial increase of engineering enrollment in the United States). Engineering and technology education for K-12 students, in my opinion, and even in the opinions of many corporate and academic leaders, such as those expressed in the Council of Competitiveness InnovateAmerica National Innovation Initiative Summit and Report (2005, Appendix A4), should not be regarded as a tax burden, but rather as a far-sighted and long-term social investment; and the principle of short-term cost-saving does NOT apply here; rather, the principle of long-term social and technological benefit should be embraced (we should always guard ourselves against being "penny-wise and pound foolish"). Science, mathematics, and technology teachers could play a subsidiary role; but they are already overburdened with teaching these tough subjects; and it is TOTALLY inappropriate to depend on them to teach engineering design (except that appropriate topics of engineering could be inserted into mathematics and science courses, ONLY as extra learning materials). Any extra expectation would NOT be sustainable; it would even be disturbing to the already fragile academic performance environment in these fields (the performance in mathematics and science of American students are no longer the highest among Western Industrialized Democracies). We are living in "a new era where the United States no longer has a comfortable lead in science, technology, and innovation […] Though scientists and engineers make up less than five percent of the population, they create up to fifty percent of our gross domestic product […] If present trends continue, 90% of all the world's scientists and engineers will be living in Asia by 2010" (Berrett, n.d.). The need for such social investment is fast becoming an emergency. We really have no time to be employing half-measures and to save pennies on engineering education.

Recruiting engineering graduates or retired engineers to teach high school students are not great options. American industries are already in shortage of engineers; schools should serve industry needs, NOT compete with them. Engineering graduates or retired engineers surely have good engineering skill sets or know the ins and outs of professional practices; but their knowledge and practices are usually limited to certain areas of engineering; and they generally are not trained in K-12 pedagogy. Thus, they could serve K-12 curriculum as consultants or substitute teachers or teacher assistants, but NOT as regular K-12 engineering and technology educators.

Professional Development for Future K-12 Engineering and Technology Teachers

My previously presented Proposed Model for Infusing Engineering Design into K-12 Curriculum (Appendix 1) has been clearly divided into four stages, with each stage requiring different types of teacher's professional development, which correspond to different characteristic of engineering and technology knowledge content and creative engineering design process:

1. <u>Kindergarten and elementary school (Grades K-5)</u>: At this stage, students would be exposed to a wide variety of science, engineering and technology projects through a variety of pedagogic methods such as educational entertainment (watching video, hands-on activities, LEGO and K'NEX projects, etc.), while learning basic mathematics skills (four operations, measurements, and others), and to creative and conceptual design of "science fiction" types. <u>Teachers' professional development</u>: Current kindergarten to elementary level teachers previously trained under traditional teacher education programs would be able to handle both academic knowledge

content and design process at this stage, as long as appropriate instructional materials are provided, and well-designed training sessions are offered. The Bachelor of Science in K-12 Engineering and Technology Teacher Education program developed under my previously presented Proposed Model (Appendix A1) has also address this issue with a course titled Creative Activities for Engineering and Technology Teachers (3 credit hours, for the 3rd year). This part of the professional development and instructional content delivery could be implemented immediately, without substantial modification of the current programs.

2. <u>Middle School (Grades 6-8)</u>: At this stage, students would learn how to conduct engineering and technology experiments and to use such experiments as a means of trial-and-error based technology design process, as well as to use traditional and modern technology as applications of engineering, such as computer-aided-design (CAD), computer-aided manufacturing (CAM), wood, plastic and metal working processes, etc., in technology design, experiment and fabrication (or construction or manufacturing). <u>Teachers' professional development</u>: Current middle and high school teachers previously trained in mathematics, science (physics and chemistry), and technology education (under the existing programs) should be able to handle both academic knowledge content and design process at this stage, as long as appropriate instructional materials are provided, and well-designed training sessions are offered. The Bachelor of Science in K-12 Engineering and Technology Teacher Education program developed under my previously presented

Proposed Model (Appendix 1) has also address this issue. This part of the professional development and instructional content delivery could be implemented immediately, without substantial modification of the current programs.

3. High school (Grades 9-11): At this stage, students would learn hard-core pre-calculus level engineering analytic principles and skills, and explore simple engineering design projects using these analytic principles and skills with the "Analytic Reduction" model of engineering design process, as well as engineering-related technology skills such as CAD and CAM. Teachers' professional development: Existing K-12 technology teacher education programs so far has not adequately prepare high school technology teachers to handle either academic knowledge content or design process to be implemented at this stage; and in my opinion, no short-term training session would adequately address this problem. The implementation of the Bachelor of Science in K-12 Engineering and Technology Teacher Education program developed under my previously proposed model (Appendix A1) would adequately address this issue.
4. High School Graduation Year (Grade 12): In this final year of high school, students would be expected to engage in moderately complex engineering design project using "System Thinking" model of engineering design. Teachers' professional development: Like in stage 3, the implementation of the Bachelor of Science in K-12 Engineering and Technology Teacher Education program developed under my previously proposed model

(Appendix A1) would adequately address this issue. This part of the professional development and instructional content delivery could be implemented once the first groups of future Bachelors of Science in K-12 Engineering and Technology Teacher Education program graduates from their respective universities.

Curricular Development

Relying on the strength of current K-12 technology curriculum developers: Many engineering analytic principles and predictive computational skills have been incorporated into existing K-12 engineering and technology curriculums, by non-profit K-12 curriculum developers such as Project Lead The Way, Engineering by Design and many others. Some of these programs are very reasonably priced. For example, according to the organization's presentation during ITEA 2009 Conference held on March 26-28 in Louisville, Kentucky, Engineering by Design (developed by International Technology Education Association, http://www.iteaconnect.org/EbD/ebd.htm) charges each participating State in the United States only $22,000 per years regardless of the number of participating high schools, for using its instructional materials (the consumables, i.e., laboratory materials, are to be purchased separately from other vendors; and some of them are available in dollar stores).

Providing guidelines is the only role for public institution to play: The major shortcoming of these programs is that they are more-or-less based on "trial-and-error" technology design process, rather than on solid engineering analytic principles and formula-based predictive computations. Nevertheless, once a Recommended List of High School Appropriate Engineering Topics is completed as an extension to this Research

Paper, the List could be made available to existing K-12 Engineering and technology curriculum developers as reference for the development of a more comprehensive set of high school engineering lessons based on solid engineering analytic predictive skills. Therefore, there is no need to create a new curricular development structure.

“Change + Continuity:” In terms of professional development, current generation of teachers educated under the existing K-12 technology education programs should continue teaching K-8 technology courses with some short-term professional training sessions. For the future, the Bachelor of Science in K-12 Engineering and Technology Teacher Education program, developed under my previously presented Proposed Model (Appendix 1) could be considered as an initial framework for preparing next generation of K-12 Engineering and Technology Curriculum teachers to teach all future K-12 engineering and technology courses.

Budgetary impact: Changes to be implemented are limited to the curricular structure of the current K-12 technology programs, which have been to a large degree implemented in Utah State University’s B.S. degree in Engineering and Technology Education (T&E in STEM) for Fall 2009; therefore, in terms of long-term budgetary matter, there would be no need to substantially increase K-12 technology teacher training budget beyond the current level.

This Research Paper will contribute to the professional development of future K-12 engineering and technology educators, in terms of defining the necessary engineering analytic and predictive principles and computational skills to be included in (1) a viable K-12 engineering curriculum; and (2) a viable K-12 engineering and technology teacher education program, which serves the needs of the future K-12 engineering curriculum.

PART SEVEN

CONCLUSIONS & RECOMMENDATIONS

The Contribution of this Research Paper

Under the general theme of systematically infusing engineering analytic and predictive principles and skills into a potentially viable future K-12 engineering education, four major topics for infusing engineering analytic knowledge content into K-12 curriculum have been explored in this Research Paper.

1. <u>Analysis of K-12 STEM instruction (Part Three, pp. 18-52)</u>: This Research Paper has presented an analysis of the mathematics and science learning of K-12 students in Georgia, at each grade level, as mandated by Georgia Performance Standards, in terms of their relevance to the goal of infusing engineering analytic and predictive principles and computation skills into a potentially viable K-12 engineering curriculum (concentrated at high school level), for the most important engineering foundation subjects. This analysis has been organized into tables that could be used to determine the necessary preparation in mathematics and science pre-requisites at each grade level throughout the entire K-12 curriculum, which is vital for a rational and scientific determination of the appropriateness of selected engineering analytic and predictive principles and computational skills for instruction at each grade level (Part Three, pp. 19-52).

2. Selection of K-12 appropriate statics topics and proposed strategies of their infusion into a potentially viable K-12 curriculum (Part Four, pp. 53-102): This Research Paper has presented an analysis of all topics of statics covered in a popular undergraduate engineering textbook (Beer et al, 2004), in terms of their required mastery of (1) mathematics skills (for carrying out predictive computation); and (2) physics principles (for understanding the underlying scientific concepts). This analysis has lead to (1) the division of all statics topics into pre-calculus and calculus-related portions; and (2) the initial determination of the appropriateness of these topics for either a focused high school subject of study at 9th Grade, or for incorporation into pre-9th Grade science coursework or into post-9th Grade AP Calculus coursework, under the "integrative STEM" and Problem-Based Learning (PBL) pedagogic models. The method of analysis used in this Research Paper could be used again in the similar analysis on other foundation engineering subjects (i.e., dynamics, strength of materials, fluid mechanics, thermodynamics, heat transfer, and engineering decision-making), or engineering major subjects (such as mechanism design). Materials for these additional subjects are ready for processing, as an extension to this Research Paper.
3. Proposed training in engineering-related calculus skills (Part Five, p. 110): This Research Paper has presented a discussion of the potential development of practical short-term training sessions on calculus skills relevant to high school engineering curriculum, which could allow high school students at 9th Grade to (1) start learning the very basics of calculus, an important branch of

mathematics that usually look “mystic” and “overwhelming” to average students; and (2) start exploring some important calculus-based engineering analytic principles and computational methods. As explained in Part Five (p. 110), this is a feasible suggestion.

4. Professional development of future K-12 engineering and technology teachers (Part Six, pp. 123-134): The vision presented in this Research Paper calls for a balance between “process-oriented engineering skills” and “core engineering concepts,” with a new focus on systematic and cohesive incorporation of engineering analytic and predictive principles and skills as a solid foundation for a potentially viable model for K-12 teachers’ professional development.

Recommendations for Further Study

To make a meaningful contribution to the implementation of a potentially viable K-12 engineering curriculum based on analytic prediction (instead of trial-and-error), further research are recommended; and these would constitute the 5th to 9th Major Thrusts of American scholars at the University of Georgia and other institutions in the endeavors to improve K-12 engineering and technology education (*Figure 11*):

- 5th Major Thrust (Extension): High school appropriate topics on engineering analytic principles and computational skills for additional subjects will be identified, using the same methods and criteria as in this Research Paper; these subjects correspond to six of the nine commonly shared undergraduate lower-division engineering foundation courses among various engineering programs at the University of Georgia (or in many other universities), listed on Table 1 (p. 19), plus two important courses that are vital to engineering design of products and systems. The progress already made in the selection of high school appropriate engineering analytic and predictive principles and skills are explained as follows:

- No need for additional work:
    - ➢ ENGR 1120 Graphics & Design: This course involves very little analytic and predictive principles and skills (generally limited to calculations of lengths, areas, angles and volumes, etc., which are more mathematics than engineering); and has been included into high school curriculum for many years.
    - ➢ ENGR 2120 Statics: High school appropriate engineering analytic principles and skills related to this subject have been already selected in this Research Paper.
    - ➢ ENGR 2920 Electrical Circuits: This subject have been extensively and cohesively included in high school engineering and technology curriculum for many years.
- Need additional work: various quantities of engineering analytic and predictive principles and skills from the following courses have been taught at high schools, but not extensively or cohesively. Thus, various amounts of works need to be done. One to two subjects could be processed during Summer 2009 at the University of Georgia; the remainder could be completed by the end of 2009.

  - ➢ ENGR 2130 Dynamics.
  - ➢ ENGR 2140 Strength of Materials.
  - ➢ ENGR 3160 Fluid Mechanics.
  - ➢ ENGR 3140 Thermodynamics.
  - ➢ ENGR 3150 Heat Transfer.
  - ➢ ENGR 2110 Engineering Decision Making.
  - ➢ Material Science.
  - ➢ Mechanical Design.
- 6th Major Thrust: Five-point Likert Scale survey study for collection of expert opinions on the various degrees of importance for various engineering analytic principles will be conducted, upon approval of NCETE leadership;
- 7th Major Thrust: An "official list of K-12 Appropriate Engineering Analytic Principles and Computational Skills" will be established, upon statistical analysis of feedbacks from the above-mentioned five-point Likert Scale Delphi survey study;
- 8th Major Thrust: National or state performance standards for K-12 engineering education could be eventually developed to incorporate (1) specific analytic principles and computational skills for various subjects, and (2) generic engineering design process. This could be a teamwork by many stakeholders;
- 9th Major Thrust (the Final): Additional high school appropriate engineering curriculum and instructional materials could be developed by various existing developers, using as reference or guidelines, the "official list" to be created in

the 7th Major Thrust, and the national or state performance standards to be developed in the 8th Major Thrust. In addition, pedagogic experiments could be conducted for the development of functional models of K-12 engineering pedagogy.

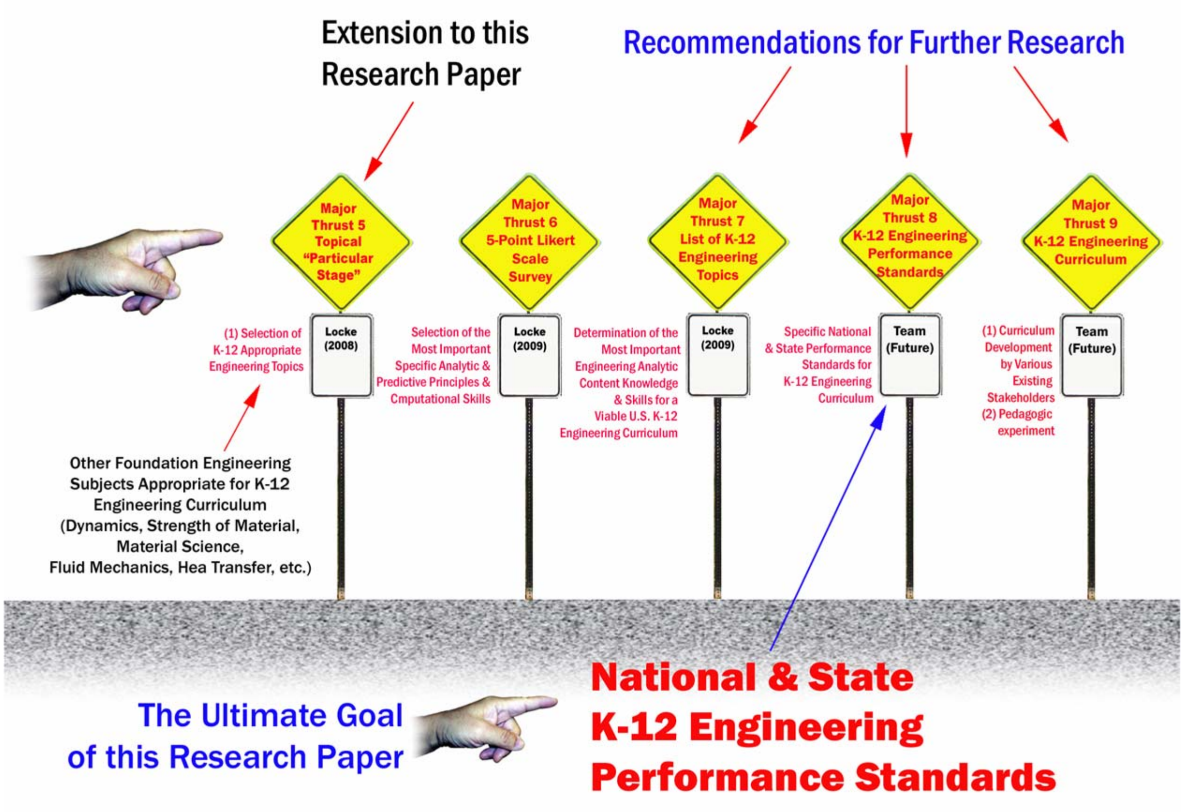


Figure 11. Recommended additional research.

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