High School Appropriate Engineering Content Knowledge: Statics

NCETE Core 4 - Engineering Design in STEM Education Research Paper

Spring 2009

College of Education, University of Georgia

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Scholarly Advice from Drs Wicklein & Lewis

- **Dr. Robert Wicklein:** Using **engineering design** as the integrating factor linking engineering and science through high school technology programs (2006, p. 25). →The infusion of engineering design includes two major components: (1) **specific engineering analytic principles and skills**; and (2) generic engineering design process.

- **Dr. Theodore Lewis:** The need to: (a). establish a "**codified body of knowledge** that can be ordered and articulated across the grades;" 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 (2007, pp. 846-848) .

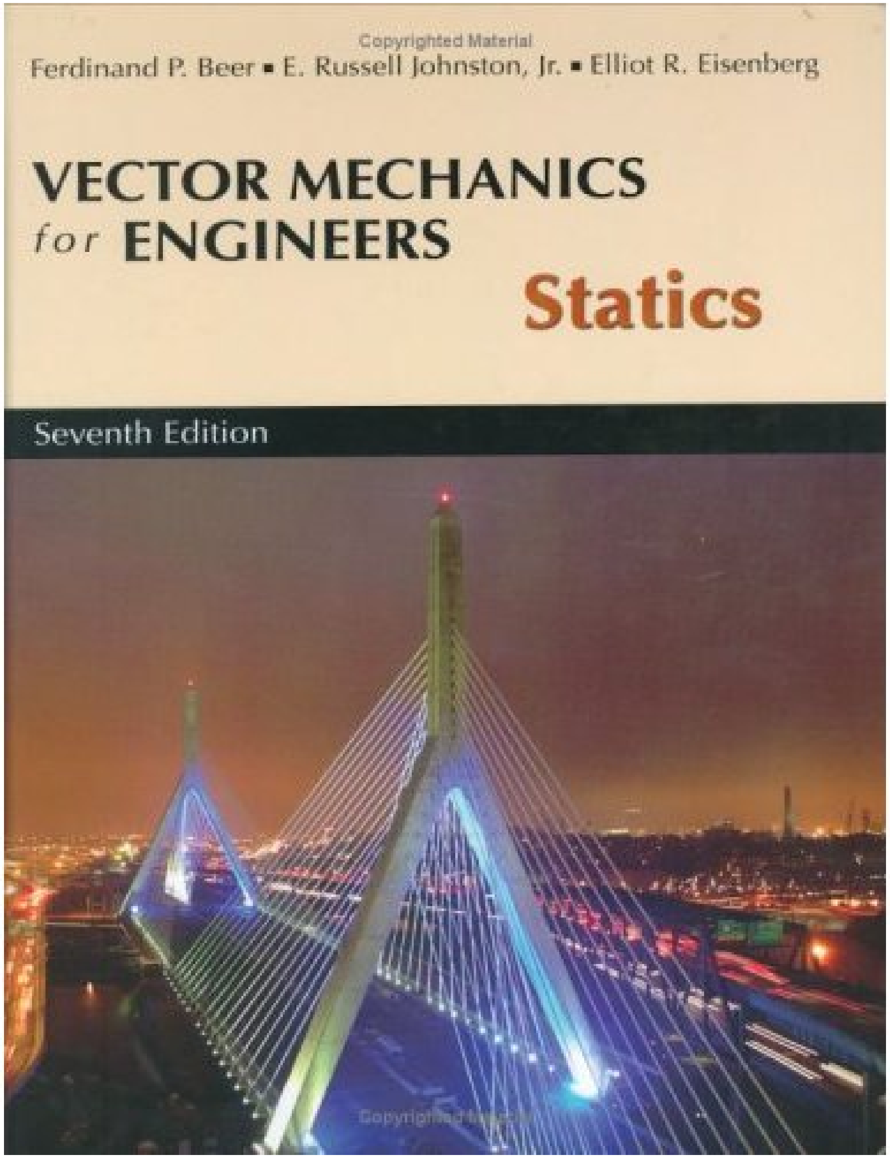
Specific Analytic Principles & Skills
+ Generic Design Process
= Engineering Design

An important component of engineering design

Ultimate goal of this Research

The Particular Purpose of the Research

- Identify high school appropriate analytic and predictive principles plus computational formulas related to the subject of **statics**;
- Using rationally established criteria and procedures.
- Using one of the most popular textbooks on statics, i.e., *Vector Mechanics for Engineers Statics, 7th Edition*, written by Ferdinand P. Beer, E. Russell Johnston, Jr., and Elliot R. Eisenberg, and published by McGraw-Hill Higher Education (2004, ISBN: 0-07-230493-6).



The Ultimate Aim of this Research & Its Connection to NCETE Research Agenda

- **A working model:** For identifying high school appropriate engineering content knowledge in other subjects: Dynamics, fluid mechanics, mechanism design, thermodynamics, heat transfer, and engineering economics or decision-making).

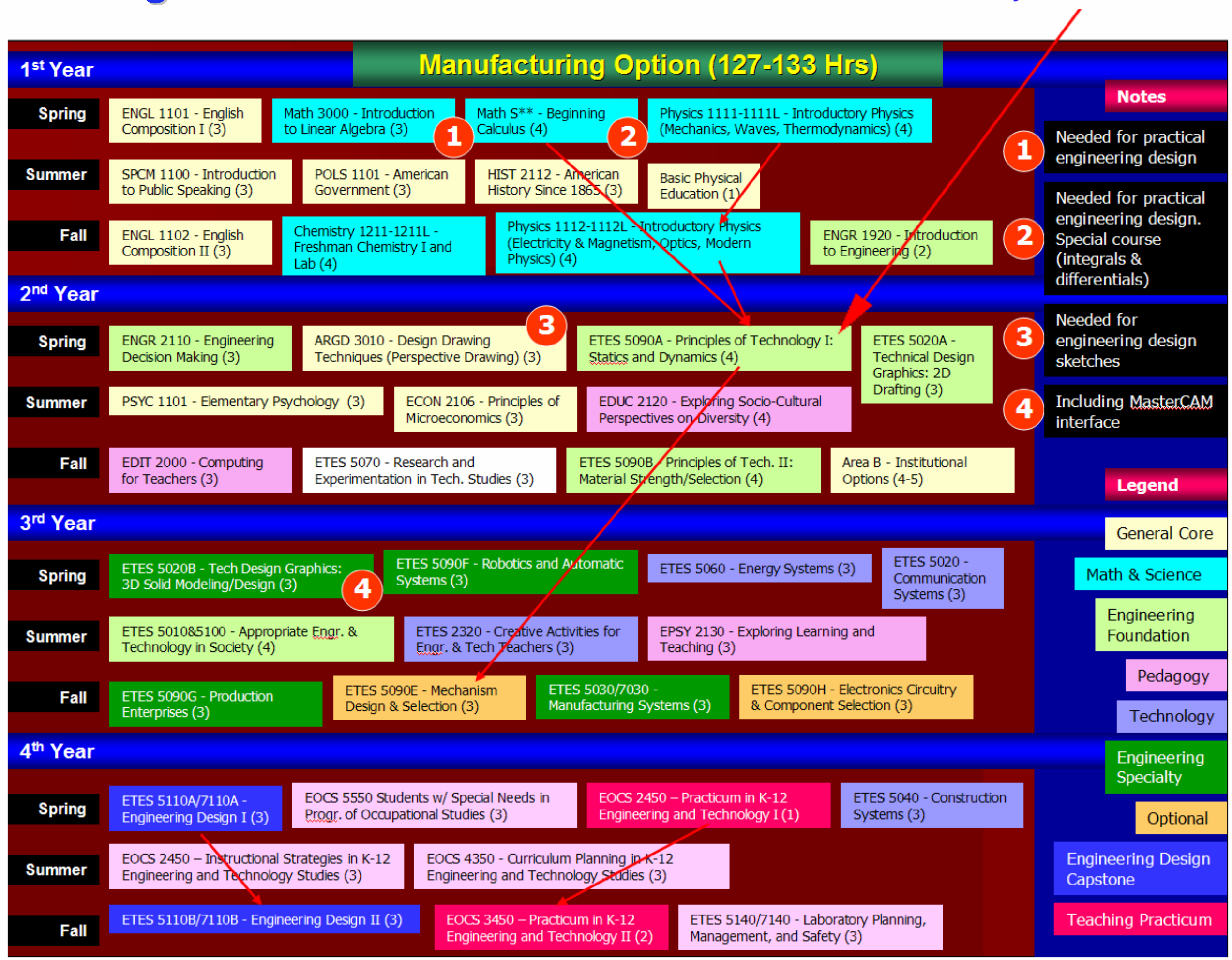
- **Ultimate goal: A list of high school appropriate topics featuring both analytic and predictive principles as well as computational formulas, to be well organized into relevant and cohesively related subjects** → A reference for systematically infusing engineering design into K-12 curriculum.

- **Relevance to NCETE agenda:** "**Professional Development Models to Infuse Engineering Design in Secondary Education**" and "**Vision and Recommendations for Engineering-Oriented Professional Development**" (Core 4 Research Paper Activity information sheet).

Research Question

- "What are the engineering analytic and predictive knowledge content in the subject of statics that are appropriate for K-12 students in various stages of their cognitive development , in terms of **matching these students' level of mastery of foundation mathematics skills, science principles and problem-solving skills**?"

Statics & Dynamics Course



Rationales for this Research Paper

To help solving the shortage in engineering graduates in the United states, by preparing K-12 students earlier than under the current system, for potential engineering majors at college level and beyond.

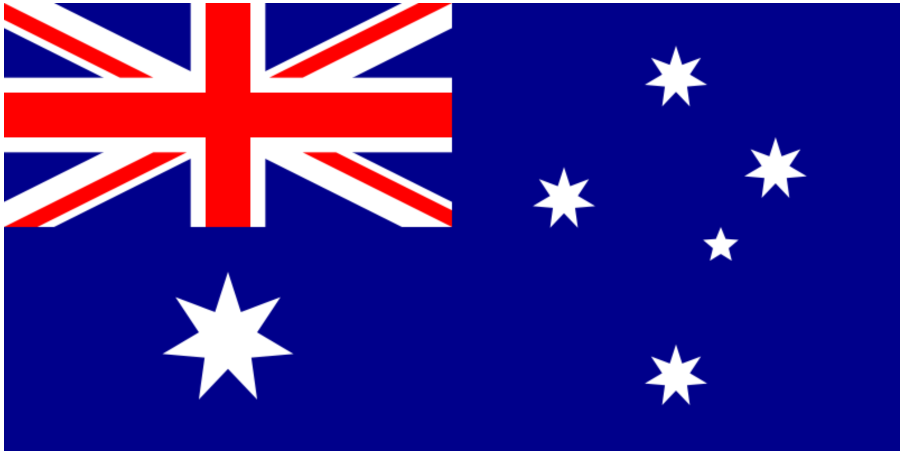
For All future K-12 students: Due to the fact that **innovation in engineering design is a vital factor in American economic growth and national defense**, it would be a wise idea to promote, among all K-12 students, basic literacy in engineering and technology, which constitute two major components of STEM (science, technology, engineering, and mathematics);

For Engineering-oriented K-12 students:

- **K-12 engineering curriculum remains skeletal so far** (main focus is on generic design process; analytic and predictive knowledge contents are restricted to a few areas, i.e., CAD, electronics, and robotics), and are generally **not cohesively and systematically organized.**
- **Engineering is a "tough" major with heavy-duty STEM content** (overwhelming to "average" students). → it would be a wise idea to streamline the learning curve by developing a **well-defined, cohesive and systematic set of content standards** would help future high school students to succeed in their engineering and technology career pathways.

Feasibility of the Research Agenda

- **STEM in K-12: Most basic scientific principles and analytic skills related to engineering design are based on pre-calculus mathematics (trigonometry, algebra, and geometry)** with occasional needs for beginning calculus (integration and differentiation). → **Pre-calculus mathematics courses are offered in most U.S. high schools**, there is a reasonable possibility that we could down-load some portions of traditional college-level engineering content knowledge to high school students.
- **Australian experience: 10% of all public high schools in Australia have implemented engineering program** (presentation, ITEA 71st Annual Conference, 2009). In the United States, → Better material conditions for improving K-12 education; thus, we could perform better than do schools in Australia.



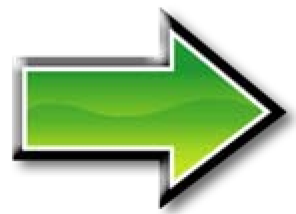
Importance of Engineering Analytic Knowledge Content

New direction:

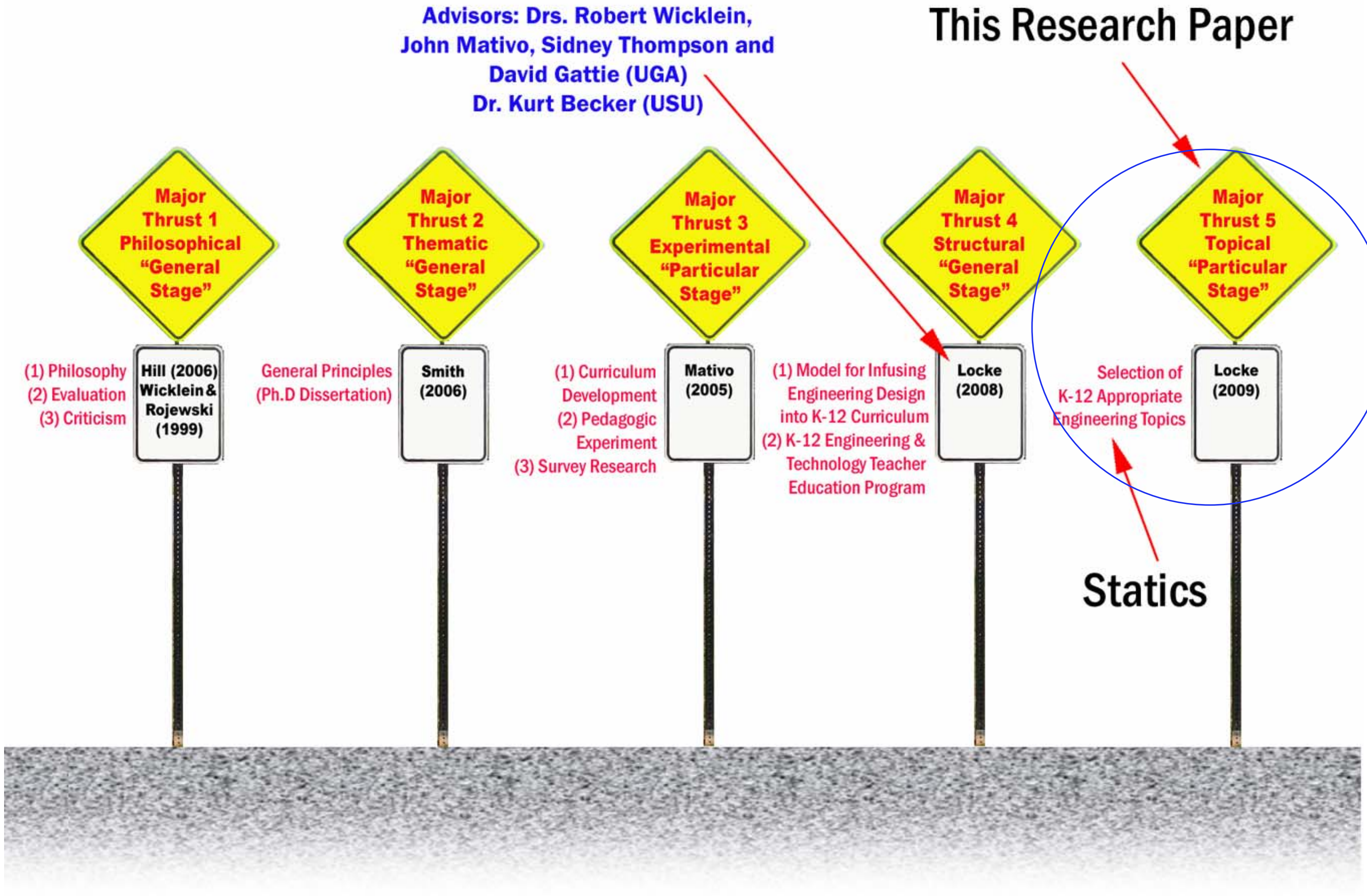
- The B.S. Degree in Engineering & Technology Education (T&E in STEM) (to be started Fall 2009 at Utah State University);
- The current B.S. in Education in Career and Technology Education Program at the University of Georgia. Both moving in this direction by including core engineering foundation subjects like statics and dynamics.

Learning from math and science curriculum:

- Engineering curriculum at K-12 level should draw extensive reference from the traditional mathematics and science pedagogy → **A full set of relevant courses, not just a few sporadic and disconnected training sessions.**
- Mastery of the “core engineering concepts” could allow 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.



Contributions of Scholars at the University of Georgia in Identifying Specific Engineering Analytic Knowledge Content for K-12 Institutions



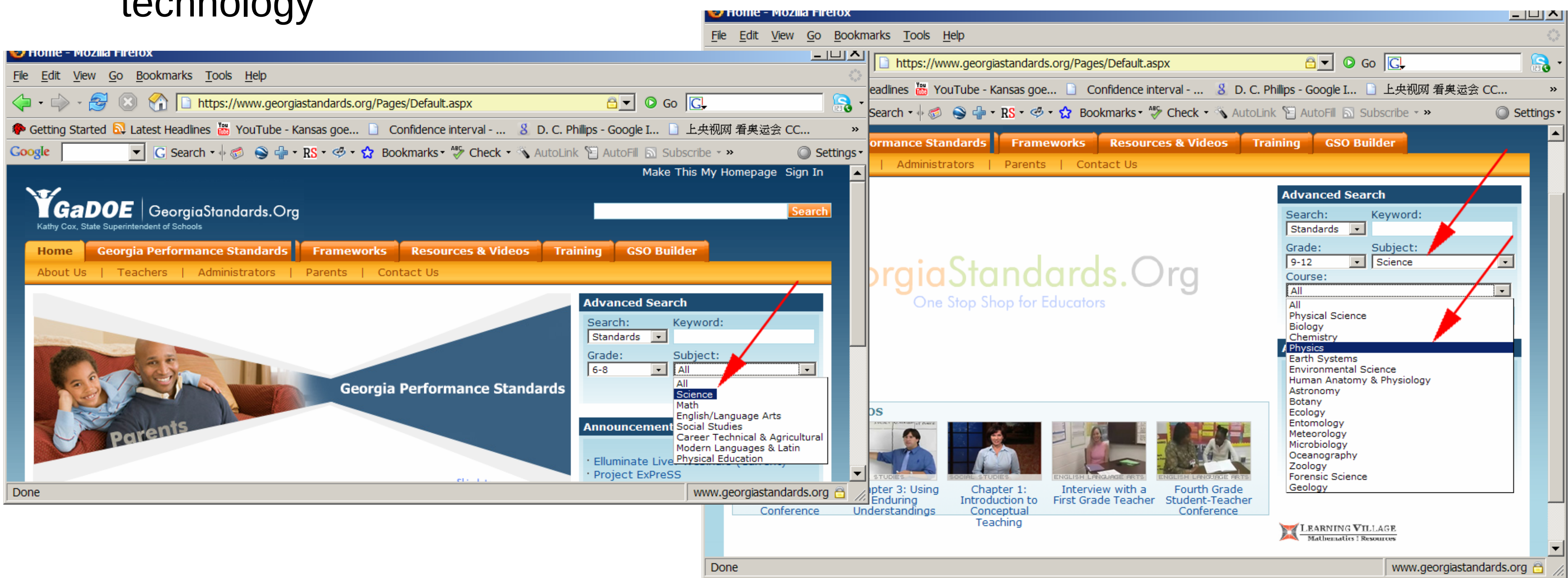
Lower-Division Engineering Foundation Course among Various Engineering Programs at the University of Georgia

University of Georgia Engineering Program	University of Georgia Engineering Foundation Courses								
	ENGR 1120 Graphics & Design	ENGR 2120 Statics	ENGR 2130 Dynamics	ENGR 2140 Strength of Materials	ENGR 3160 Fluid Mechanics	ENGR 3140 Thermo-dynamics	ENGR 3150 Heat Transfer	ENGR 2920 Electrical Circuits	ENGR 2110 Engr. Decision Making
B.S. in Agricultural Engineering									
Electrical & Electronic Systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mechanical Systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
Natural Resource Management	✓	✓	✓	✓	✓	✓	✓	✓	✓
Structural Systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
Process Operations	✓	✓	✓	✓	✓	✓	✓	✓	✓
B.S. EnvE Environmental Engineering									
Energy/Water Resources		✓		✓	✓				
Infrastructure/ Planning/ Economics		✓		✓	✓				
B.S. in Biological Engineering									
Environmental Area of Emphasis	✓	✓		✓	✓	✓	✓	✓	✓
Biochemical Area of Emphasis	✓	✓		✓	✓	✓	✓	✓	✓
Biomedical Area of Emphasis •Biomechanics Track •Instrumentation Track	✓	✓		✓	✓	✓	✓	✓	✓
Computer Systems Engineering Program									
Computer Hardware Systems	✓	✓						✓	✓
Mechatronics	✓	✓						✓	✓
Telecommuni-cations & Wireless Systems	✓	✓						✓	✓
Software Engineering	✓	✓						✓	✓
Biological Systems	✓	✓						✓	✓
Graphics & Visualization	✓	✓						✓	✓

Sections of Georgia Performance Standards Directly Relevant to the Infusion of Engineering Analytic Content Knowledge into the K-12 Curriculum

https://www.georgiastandards.org/Pages/Default.aspx

- Mathematics,
- Science;
- Career, Technical, and Agricultural Education (CTAE). → Engineering and technology



Why Georgia Performance Standards?

- "The Georgia Performance Standards are the result of months of work by teacher teams, state and national experts, and consultants" who "**looked at national standards from high-performing states such as Michigan, Texas, and North Carolina, and nations such as Japan, and consulted the guidelines of national groups such as the National Council of Teachers of Mathematics and the American Association for the Advancement of Science**" (GeorgiaStandards.org, 2009).

- The average K-12 students' academic performance mandated by Georgia Performance Standards is **somewhere between the highest and lowest among all fifty states in the United States**; therefore, it is conveniently chosen as **a typical model** that could be considered as applicable to most states in the Nation.

- "The performance standards provide clear expectations for instruction, assessment, and student work. […] isolate and identify the skills needed to use the knowledge and skills to problem-solve, reason, communicate, and make connections with other information" → **Used to delineate the required or expected mastery of math and science content knowledge at all grade levels throughout the K-12 system in the State of Georgia.**

Selection of Mathematics Course Sequence Options

GeorgiaStandards.Org
GATEWAY TO EDUCATION & PROFESSIONAL RESOURCES
One Stop Shop For Educators

5/07

Georgia Department of Education
Secondary Mathematics
Guidance for Course Sequences under the Georgia Performance Standards

Georgia Performance Standards (GPS) Math Course Sequence					
	Option 1	**Option 2**	**Option 3**	**Option 4**	**Option 5**
Grade			**Advanced**	**Accelerated**	**Accelerated**
6th	6th Grade GPS	6th Grade GPS	6th Grade Advanced GPS	6th, 7th, and 8th grade GPS	6th, 7th, and 8th grade GPS
7th	7th Grade GPS	7th Grade GPS	7th Grade Advanced GPS		
8th	8th Grade GPS	8th Grade GPS	8th Grade Advanced GPS	Math 1	Accelerated Math 1
9th	Math 1	Accelerated Math 1	Accelerated Math 1	Math 2	Accelerated Math 2
10th	Math 2	Accelerated Math 2	Accelerated Math 2	Math 3	Accelerated Math 3
11th	Math 3	Accelerated Math 3	Accelerated Math 3	Math 4	AP Statistics*; AP Calculus AB/BC; Joint Enrollment
12th	Math 4; AP Statistics*; Discrete Math	AP Calculus AB/BC; AP Statistics*; Discrete Math; Joint Enrollment	AP Calculus AB/BC; AP Statistics*; Discrete Math; Joint Enrollment	AP Calculus AB; AP Statistics*; Discrete Math; Joint Enrollment	AP Statistics*; AP Calculus AB/BC; Joint Enrollment

*AP Statistics may be taken concurrently with an upper level math course at the system's discretion.

Option 2 and Option 3 are established **for average (or "middle grade") students**

All Options could lead to AP (Advanced Placement) Calculus course at 12th grade or even 11th grade (for Option 5 only). → Preparing students for engineering analytic courses at undergraduate lower-division level.

- Option 1: This option includes grade-level standards and tasks for middle grade students. After Math 3 students may take Math 4, AP Statistics, Discrete Mathematics or a fourth year GPS math course.
- Option 2: This option includes grade-level standards and tasks for middle grade students. It is possible for students who successfully complete middle grades standards to take Accelerated Mathematics. After Accelerated Math 3 students may take AP Calculus AB, AP Calculus BC, AP Statistics, Discrete Mathematics, a fourth year GPS mathematics course related to student interest, or an appropriate post-secondary option.
- Option 3: This option includes grade-level standards with enhanced and more complex tasks for middle grades students. These tasks will be provided by the GaDOE. After Accelerated Math 3 students may take AP Calculus AB, AP Calculus BC, AP Statistics, Discrete Mathematics, a fourth year GPS mathematics course related to student interest, or an appropriate post-secondary option.
- Option 4: This option requires the compacting of three years of middle grades standards into two years. After Math 4 students should be prepared to take AP Calculus AB, AP Statistics, Discrete Mathematics, a fourth year GPS mathematics course related to student interest, or an appropriate post-secondary option.
- Option 5: This option is for a few students who are highly talented in mathematics. It requires the compacting of three years of middle grades standards into two years. After Accelerated Math 3, students may take AP Calculus AB, AP Calculus BC, AP Statistics, Discrete Mathematics, a fourth year GPS mathematics course related to student interest, or an appropriate post-secondary option such as multivariable calculus.
- *Figure 3. Grades 6-12 mathematics courses under Georgia Performance Standards (source: from the website https://www.georgiastandards.org/Standards/Pp./BrowseStandards/MathStandards.aspx, under the "Middle School Math Acceleration" link; file name: MS-Math-Acceleration).*

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7th	7th Grade GPS	7th Grade GPS	7th Grade Advanced GPS		
8th	8th Grade GPS	8th Grade GPS	8th Grade Advanced GPS	Math 1	Accelerated Math 1
9th	Math 1	Accelerated Math 1	Accelerated Math 1	Math 2	Accelerated Math 2
10th	Math 2	Accelerated Math 2	Accelerated Math 2	Math 3	Accelerated Math 3
11th	Math 3	Accelerated Math 3	Accelerated Math 3	Math 4	AP Statistics*; AP Calculus AB/BC; Joint Enrollment
12th	Math 4; AP Statistics*; Discrete Math	AP Calculus AB/BC; AP Statistics*; Discrete Math; Joint Enrollment	AP Calculus AB/BC; AP Statistics*; Discrete Math; Joint Enrollment	AP Calculus AB; AP Statistics*; Discrete Math; Joint Enrollment	AP Statistics*; AP Calculus AB/BC; Joint Enrollment

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Option 2 and Option 3 are established **for average (or "middle grade") students**

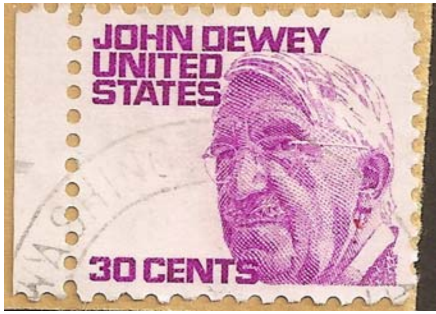
All Options could lead to AP (Advanced Placement) Calculus course at 12th grade or even 11th grade (for Option 5 only). → Preparing students for engineering analytic courses at undergraduate lower-division level.

- **Options 2 and 3 (for "average" students):** Selected for determining the completion of mathematics preparation for infusing engineering analytic content knowledge into any particular grade level throughout the K-12 curriculum (mostly at 9th to 12th Grades, or at high school level).
- **For students enrolled in the Options 4 Math Course Sequence:** such determination will still apply.
- **For students enrolled in the Options 5 Math Course Sequence:** such determination could be adjusted in terms of allowing mathematically "highly-talented" students to enroll in engineering analytic courses at one grade prior to the grade determined for other options.

Why Options 2 & 3 for "Average" students?

An urgent need to increase opportunities for average U.S. domestic students to choose engineering as a "doable" and viable career.

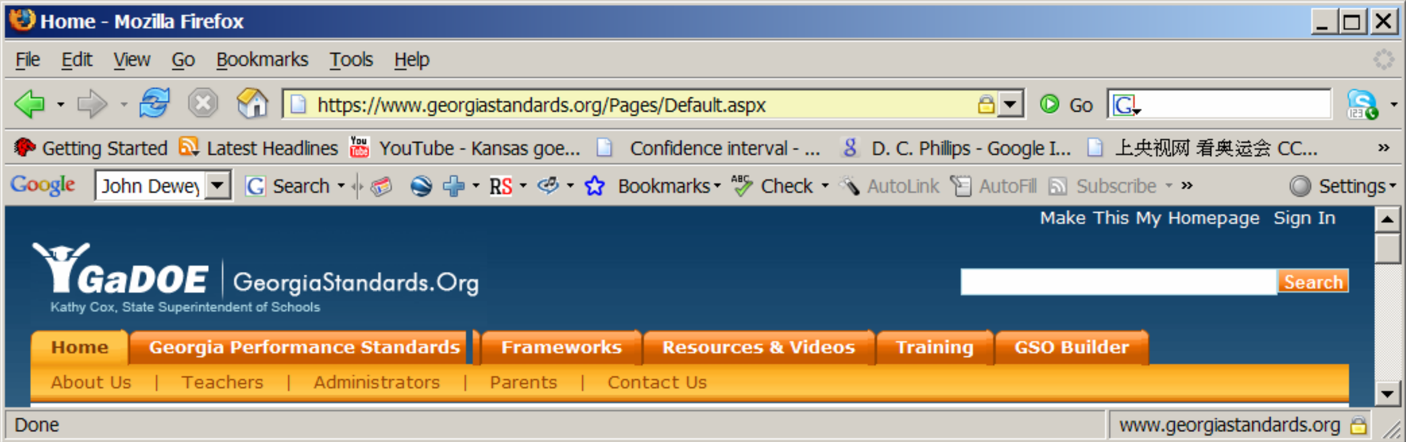
- The U.S. share of the percentage of all engineers in the whole world has **dropped from close to 25% at the end of World War Two to an alarming figure of much less than 5% today**;
- India nowadays educates greater number of engineers per year with strongly competitive quality that is based on a standard British model of science and engineering education, and **close to 50% of all graduates form B.S. engineering programs from India's top schools come to the United States to pursue masters' and doctoral degrees**; work for top U.S. corporations, research laboratories and universities for a few years to grasp the best U.S. technology and finally bring the best fruits of American engineering education to India, **making India a rapidly rising international engineering and economic power house** to compete against traditional global leaders in science, engineering and technology, such as the United States, Great Britain, Germany and Japan;
- The United States has been in **chronic shortage of engineering graduates in the past decades**.



Engineering Literacy for Average Americans!

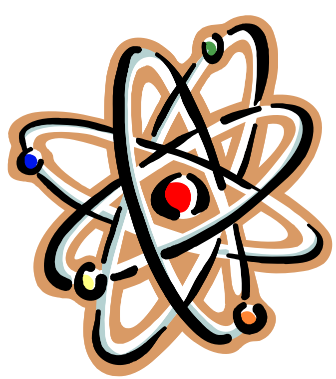
To achieve American independence on engineering talent pool: The strategic development of a viable K-12 engineering curriculum for the majority of "average" students, instead of just for a minority of "highly talented" ones.

- Not all of these mathematically "highly-talented" students will pursue engineering (many will go to non-STEM professions that pay more but require less heavy-duty training in STEM).
- **Focusing on the "average" students could guide more high school students to engineering pathways and help reversing the shortage problem into a potential surplus in the future.**



Georgia Performance Standards

Relevant to the Infusion of Engineering Analytic Content Knowledge throughout the K-12 Curriculum



Needed Mathematics Preparations

For average K-12 student enrolled in engineering *Career Pathways*:

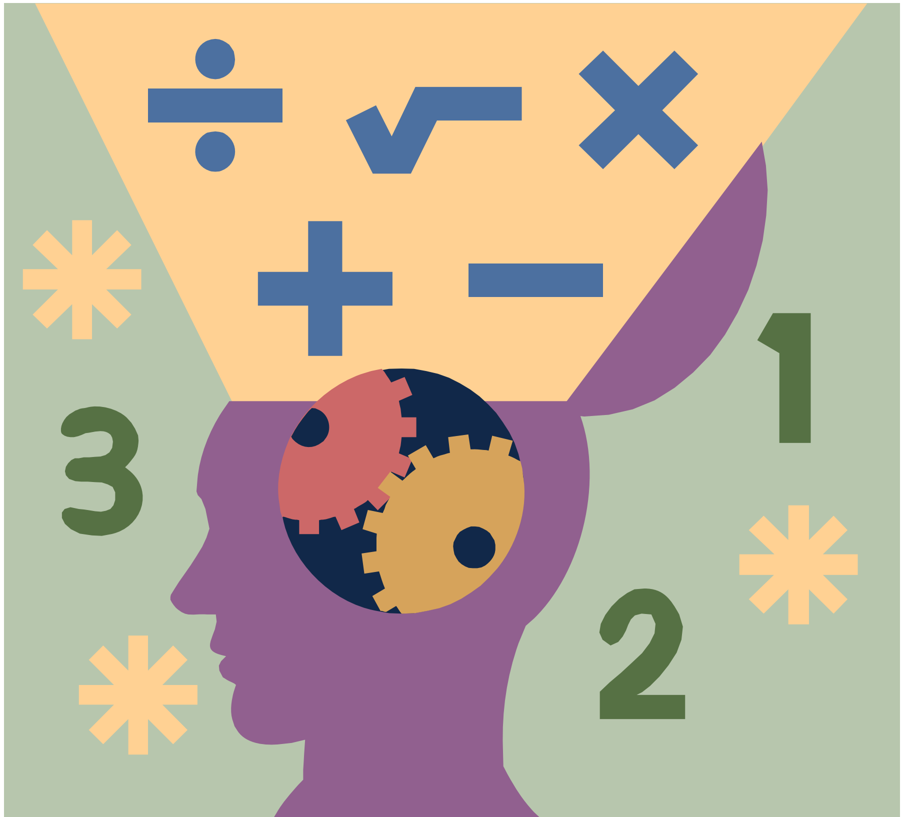
- **Four operations:** (1) addition; (2) subtraction; (3) multiplication; and (4) division. Sigma notations could be used to represent these four basic computations.
- **System of numbers:** (1) whole numbers; (2) decimals; (3) fractions; (4) roots and powers; (5) irrational numbers; and (6) rounding rules.
- **Measurements:** (1) dimensions (length, area and volume); (2) time; (3) mass; (4) temperature.
- **Systems of units:** (1) metric; (2) customary; and (3) conversion between metric and customary units, or among units in the same system.
- **Geometry:** (1) the Cartesian Coordinates System; (2) two-dimensional shapes, their perimeters, areas and other characteristics; and (3) three-dimensional solids, their edge lengths, surface areas, volumes and other perimeters. For regular shapes and solids, these perimeters can be calculated using pre-calculus mathematics; for irregular shapes and solids, calculus (mainly integration) is needed.
- **Trigonometry:** (1) the six trigonometric functions; (2) special triangles (isosceles, equilateral, etc.); (3) Laws of Sins and Cosines; and (4) triangulation (for structural design and development of sheet-metal parts).
- **Algebra:** (1) algebraic modeling; (2) simultaneous equations; and (3) linear algebra.
- **Vector graphics:** (1) in two-dimensional plane; and (2) in three-dimensional space; and (3) parallelogram rules for addition and subtraction of vectors.

For average college student enrolled in engineering undergraduate programs:

- All of the above plus
- **Beginning Calculus:** (1) integration (single and multiple variables); (2) differentiation (full and partial derivatives).
- **Advanced calculus:** differential equations.

High School Mathematics

- **The most frequently used math skills in practical engineering design:** (1) **four operations**; (2) **geometry and trigonometry**; (3) **linear algebra**; and (4) **beginning calculus** (**All in US K-12 curriculum**).



Mathematics

Table 2A (Number, Four Operations & Algebra Topics for Grades K-8):

- Basics of four arithmetic operations, i.e., addition, subtraction, multiplication and division, are required at Grade 2;
- Four operations involving decimals, fractions, signs and other numeric elements are required for completion at Grade 7; and
- Basics of systems of simultaneous equations and inequalities are required at Grade 8 (pp. 29-30).

Table 2A
Grades K-8 Number, Four Operations & Algebra Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Number, Four Operations & Algebra Topics
K	o Addition and subtraction (MKN2) o Connecting numbers to quantities (MKN1)
1	o Whole numbers, number sets and decimal notations (M1N1, M1N2) o Addition and subtraction (M1N3) o Division (M1N4)
2	o Multi-digit addition and subtraction (M2N2) o Multiplication and division (M2N3) o Fractions (M2N4)
↑	Four Operations Basics Completed ↑
3	o Addition and subtraction (M3N2) o Multiplication and division of whole numbers (M3N3) (M3N4) o Decimals and common fractions and problem-solving (M3N5)
4	o Representing unknowns using symbols (M4A1) o Graphical representations for a given set of data (M4D1) o Rounding numbers (M4N2) o Whole numbers in the base-ten numeration system (M4N1) o Decimals (M4N5) o Common fractions (M4N6)
5	o Multiplication and division with decimals (M5N3) o Division of whole numbers as a fraction (M5N4) o Set of counting numbers, subsets, odd/even, prime/composite; multiples and factors, divisibility rules) (M5N1) o Percentage (M5N5) o Simple algebraic expressions by substituting numbers for the unknown (M5A1)
6	o Ratio. (M6A1) o Four arithmetic operations for positive rational numbers (factors, multiples, prime factorization, Fundamental Theorem of Arithmetic, Greatest Common Factor, Least Common Multiple, fractions and mixed numbers with unlike denominators) (M6N1) o Algebraic expressions including exponents, and solution of simple one-step equations using each of the four basic operations (M6A3)
7	o Four operations with positive and negative rational numbers (absolute value of a number, repeating decimals) (M7N1) o Representing and evaluating quantities using algebraic expressions (translation from verbal phrases, simplification and evaluation using commutative, associative, and distributive properties; addition and subtraction of linear expressions) (M7A1) o Linear equations in one variable (using the addition and multiplication properties of equality to solve one- and two-step linear equations) (M7A2)
↑	Four Operations Completed ↑
8	o Basic concepts of set theory (Venn diagrams, subsets, complements, intersection, and union of sets, set notation) (M8D1) o Number of outcomes related to a given event. (tree diagrams, addition and multiplication principles of counting) (M8D2) o Different representations of numbers including square roots, exponents, and scientific notation. (M8N1) o Solving algebraic equations in one variable with absolute values; and solving equations involving several variables for one variable in terms of the others (M8A1) o Systems of linear equations and inequalities and problem-solving. (M8A5)
↑	Basic Algebra Completed ↑

Mathematics

Table 2B (Geometry for Grades K-8):

- The coordinate system, one among the most important constructs for engineering analysis and design, is required at Grade 4; and
- The characteristics of common two-dimensional figures (triangle, square, rectangle, circle, and of three-dimensional solids, such as cone, pyramid, prism, their surface and volume, are required for learning at Grade 8) (pp. 30-31).

Table 2B
Grades K-8 Geometry Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Geometry Topics
K	o Plane geometric figures (triangles, rectangles, squares, and circles) and solid geometric bodies (spheres and cubes) (MKG1)
1	o Spatial relations (proximity, position, and direction) (M1G3) o Plane geometric figures (squares, circles, triangles, and rectangles, pentagons, and hexagons) and solid geometric figures (cylinders, cones, and rectangular prisms) (M1G1) (M1G2)
2	o Plane figures (triangles, squares, rectangles, trapezoids, quadrilaterals, pentagons, hexagons, and irregular polygonal shapes) (M2G1) o Solid geometric figures (prisms, cylinders, cones, and spheres) (M2G2)
3	o Perimeter and area of geometric figures (squares and rectangles). (M3M3) (M3M4) o Properties of geometric figures (scalene, isosceles, and equilateral triangles; center, diameter, and radius of a circle) (M3G1)
4	o Characteristics of geometric figures (parallel and perpendicular lines in parallelograms, squares, rectangles, trapezoids, and rhombi) (M4G1) o Fundamental solid figures (cube and rectangular prism) (M4G2) o Coordinate system (M4G3)
↑	**Coordinate System Completed** ↑
5	o Congruence of geometric figures and correspondence of their vertices, sides, and angles. (M5G1) o Relationship of the circumference of a circle, its diameter, and π (M5G2) o Area (parallelogram, triangle, circle, regular and irregular polygon) (M5M1) o Volume (cube and rectangular prism) (M5M4)
6	o Plane figures (lines of symmetry, degree of rotation, concepts of ratio, proportion, and scale factor) (M6G1) o Solid figures (right prisms, pyramids, cylinders, cones; front, back, top, bottom, and side views; nets for prisms, cylinders, pyramids, and cones) (M6G2) o Volume (right rectangular prisms, cylinders, pyramids, and cones) (M6M3) o Surface area (right rectangular prisms and cylinders) (M6M4)
7	o Geometric construction of plane figures (M7G1) o Transformations (translations, dilations, rotations, reflections), and the resulting coordinates (M7G2) o Properties of similarity in geometric figures (similarity, congruence, scale factors, length ratios, and area ratios, etc.) (M7G3) o Three-dimensional figures formed by translations and rotations of plane figures through space, sketching, modeling, and describing cross-sections of cones, cylinders, pyramids, and prisms) (M7G4)
8	o Properties of parallel and perpendicular lines and the meaning of congruence (M8G1) o Pythagorean theorem (M8G2)
↑	**Basic 2D & 3D Geometric Figure, Areas and Volumes Completed** ↑

Mathematics

Table 2C (Measurement & Comparison for Grades K-8):

- Basics of standard units for length, time and temperature are required for completion at Grade 2; and
- Units conversion and units for area and volume are required for completion at Grade 8 (pp. 31-32).

Table 2C
Grades K-6 Measurement & Comparison Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Measurement & Comparison Topics
K	o Length, capacity, height and weight (MKM1) o Calendar time (MKM2) o Ordering of events (MKM3)
1	o Length, weight, or capacity (M1M1) o Time (M1M2)
2	o Standard units of inch, foot, yard, and metric units of centimeter and meter (M2M1) o Time (M2M2) o Temperature (M2M3)
↑	↑ Standard Units (Length, Time & Temperature) Completed ↑
3	o Elapsed time of a full, half, and quarter-hour (M3M1) o Length measurement with appropriate units and tools (M3M2)
4	o Weight (M4M1) o Angle (M4M2)
5	o Capacity with units and tools (milliliters, liters, fluid ounces, cups, pints, quarts, and gallons) (M5M3)
6	o Unit conversion within one system of measurement (customary or metric) by using proportional relationships (for length, perimeter, area, and volume) (M6M1) o Units of measure for length, perimeter, area, and volume (M6M2)
↑	↑ Unit Conversion Completed ↑

Mathematics

Table 2D (Data Analysis, Probabilities & Statistics for Grades K-8):

- For the particular subject of statics, the relevance of Performance Standards listed in this table are generic and marginal; and this is equally true for many other engineering foundation subjects (p. 32).

Table 2D
Grades K-8 Data Analysis, Probabilities & Statistics Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Data Analysis, Probabilities & Statistics Topics
K	o Data collection and organization (MKD1)
1	o Tables and graphs (creation, interpretation and data entry (M1D1)
2	o Tables and graphs (M2D1)
3	o Creation and interpretation of simple tables and graphs and mathematical arguments and proofs (M3D1)
5	o Analysis of graphs (circle, line, bar graphs, etc.) (M5D1) o Collection, organization, and display of data using the most appropriate graph (M5D2)
6	o Posing questions, collecting data (through surveys or experiments), representing and analyzing the data (categorical or numerical), and interpreting results (frequency distributions and tables, pictographs, histograms; bar, line, and circle graphs; and line plots) (M6D1) o Experimental and simple theoretical probability, the nature of sampling, and predictions from investigations (M6D2)
7	o Understanding and graphing relationships between two variables. (M7A3) o Data collection and statistic analysis (frequency distributions, mean, median, mode, outliers, range, quartiles, interquartile range, graphs including pictographs, histograms, bar, line, and circle graphs, and line plots, box-and-whisker plots and scatter plots, description of the relationship between two variables, etc.) (M7D1)
8	o Understanding and graphing inequalities in one variable. (M8A2) o Relations and linear functions. (M8A3) o Graphing and analyzing graphs of linear equations and inequalities. (M8A4) o Basic laws of probability (probabilities of simple independent events and of compound independent events) (M8D3) o Organizing, interpreting, and making inferences from statistical data (data collection, modeling with a linear function, line of best fit from a scatter plot) (M8D4)

Mathematics

Table 2E (Number, Operations & Functions Topics for Grades 9-12):

- The Georgia Performance Standards for the six trigonometric functions in this section are directly relevant to many topics of statics (p. 33).

Table 2E
Grades 9-12 Number, Operations & Functions Topics Completion Chart
(According to Georgia Performance Standards)

Course/Grades	Number, Operations & Functions Topics
Accelerated Mathematics 1 (Grades 9, 10, 11, 12) (To be applied at Grade 9 under Math Course Sequence Options 2 & 3)	o Complex numbers (MA1N1) o Transformations of basic functions (vertical shifts, stretches, shrinks; reflections across the x- and y-axes; domain, range, zeros, intercepts, intervals of increase and decrease, maximum and minimum values; end behavior; rates of change of linear, quadratic, square root, and other function families) (MA1A1) o Simplification and operation with radical expressions, polynomials, and rational expressions (square roots, special products; area and volume models) (MA1A2) o Characteristics of quadratic functions, including domain, range, vertex, axis of symmetry, zeros, intercepts, extrema, intervals of increase and decrease, and rates of change; arithmetic series and various ways of computing their sums; sequences of partial sums of arithmetic series as examples of quadratic functions) (MA1A3) o Solving quadratic equations and inequalities in one variable (MA1A4) o Step and piecewise functions, greatest integer and absolute value functions (MA1A5)
Accelerated Mathematics 2 (Grades 9, 10, 11, 12) (To be applied at Grade 10 under Math Course Sequence Options 2 & 3)	o Exponential functions. (MA2A1) o Inverses of functions. (MA2A2) o Analyze graphs of polynomial functions of higher degree. (MA2A3) o Logarithmic functions as inverses of exponential functions. (MA2A4) o Equations and inequalities (real and complex roots of higher degree polynomial equations using the factor theorem, remainder theorem, rational root theorem, and fundamental theorem of algebra, incorporating complex and radical conjugates; polynomial, exponential, and logarithmic equations and inequalities; solution sets of inequalities with interval notation) (MA2A5)
Accelerated Mathematics 3 (Grades 9, 10, 11, 12) (To be applied at Grade 11 under Math Course Sequence Options 2 & 3)	o Complex numbers in trigonometric form. (MA3A11) o Sequences and series (MA3A9) o Rational functions (domain, range, zeros, points of discontinuity, intervals of increase and decrease, rates of change, local and absolute extrema, symmetry, asymptotes, and end behavior; inverses of rational functions, domain and range, symmetry, and composition; solving rational equations and inequalities analytically and graphically) (MA3A1) o Parametric representations of plane curves (conversion between Cartesian and parametric form; graph equations in parametric form showing direction and beginning and ending points where appropriate) (MA3A12) o Polar equations (expressing coordinates of points in rectangular and polar form; graphing and identifying characteristics of simple polar equations including lines, circles, cardioids, limacons, and roses) (MA3A13) o Using the circle to define the trigonometric functions (angles measured in degrees and radians, including but not limited to 0°, 30°, 45°, 60°, 90°, their multiples, and equivalences; the six trigonometric functions as functions of general angles in standard position; values of trigonometric functions using points on the terminal sides of angles in the standard position; the six trigonometric functions as functions of arc length on the unit circle; finding values of trigonometric functions using the unit circle) (MA3A2) o Graphs of the six trigonometric functions (characteristics of the graphs of the six basic trigonometric functions; graphing transformations of trigonometric functions including changing period, amplitude, phase shift, and vertical shift; applying graphs of trigonometric functions in realistic contexts involving periodic phenomena) (MA3A3) o Investigate functions (comparing and contrasting properties of functions within and across the following types: linear, quadratic, polynomial, power, rational, exponential, logarithmic, trigonometric, and piecewise; transformations of functions; characteristics of functions built through sum, difference, product, quotient, and composition) (MA3A4)

Mathematics

Table 2F (Trigonometry & Analytic Geometry Topics for Grades 9-12):

- The Georgia Performance Standards for the relevant topics will prepare students for undergraduate engineering courses (p. 34).

Table 2F
Grades 9-12 Trigonometry & Analytic Geometry Topics Completion Chart
(According to Georgia Performance Standards)

Course/Grades	Trigonometry & Analytic Geometry Topics
Accelerated Mathematics 1 (Grades 9, 10, 11, 12) (To be applied at Grade 9 under Math Course Sequence Options 2 & 3)	o Properties of geometric figures in the coordinate plane (distance between two points, between a point and a line; midpoint of a segment, properties and conjectures of triangles and quadrilaterals) (MA1G1) o Properties of triangles, quadrilaterals, and other polygons (sum of interior and exterior angles; triangle inequality, side-angle, and exterior-angle inequality; congruence postulates and theorems for triangles: SSS, SAS, ASA, AAS, HL; properties of special quadrilaterals: parallelogram, rectangle, rhombus, square, trapezoid, and kite; points of concurrency in triangles, such as incenter, orthocenter, circumcenter, and centroid) (MA1G3) o Properties of circles (chords, tangents, and secants as an application of triangle similarity; central, inscribed, and related angles; length of an arc and the area of a sector) (MA1G4) o Measures of spheres (surface area and volume) (MA1G5)
Accelerated Mathematics 2 (Grades 9, 10, 11, 12) (To be applied at Grade 10 under Math Course Sequence Options 2 & 3)	o Special right triangles (30°-60°-90°; and 45°-45°-90° triangles) (MA2G1) o Defining and applying sine, cosine, and tangent ratios to right triangles (MA2G2) o Relationships between lines and circles. (MA2G3) o Recognizing, analyzing, and graphing the equations of the conic sections (parabolas, circles, ellipses, and hyperbolas). (MA2G4) o Investigate planes and spheres (vertex of a rectangular prism; distance formula in 3-space; equations of planes and spheres) (MA2G5)
Accelerated Mathematics 3 (Grades 9, 10, 11, 12) (To be applied at Grade 11 under Math Course Sequence Options 2 & 3)	o Simplifying trigonometric expressions and verifying equivalence statements (MA3A5) o Solve trigonometric equations both graphically and algebraically (solving trigonometric equations over a variety of domains, using the coordinates of a point on the terminal side of an angle to express x as r cos θ and y as r sin θ, law of sines and the law of cosines) (MA3A6) o Verifying and applying ½ab sin C to find the area of a triangle (MA3A7) o Inverse sine, inverse cosine, and inverse tangent functions. (MA3A8)

Mathematics

Table 2G (Linear Algebra Topics for Grade 10):

- Linear algebra is among the most important mathematics skill for practical engineering design (p. 34).

Table 2G
Grades 9-12 Linear Algebra Topics Completion Chart
(According to Georgia Performance Standards)

Course	Linear Algebra Topics
Accelerated Mathematics 2 (Grades 9, 10, 11, 12) (To be applied at Grade 10 under Math Course Sequence Options 2 & 3)	○ Basic operations with matrices (adding, subtracting, multiplying, and inverting two-by-two and larger matrices) (**MA2A6**) ○ Using matrices to formulate and solve problems (representing a system of linear equations as a matrix equation; solve matrix equations using inverse matrices, represent and solve realistic problems using systems of linear equations) (**MA2A7**) ○ Solving linear programming problems in two variables (solve systems of inequalities in two variables, showing the solutions graphically; represent and solve realistic problems using linear programming) (**MA2A8**) ○ Matrix representations of vertex-edge graphs (**MA2A9**)

Mathematics

Table 2H (Vector Graphics Topics for Grade 11):

- Vectors expression with rectangular coordinates, magnitude and direction, plus their addition and subtraction could be taught at Grade 9 since its basic mathematics pre-requisite, i.e., the six trigonometric functions (sine, cosine, tangent, cotangent, secant and cosecant) are required for Grade 9 (p. 35).

Table 2H
Grades 9-12 Vector Graphic Topics Completion Chart
(According to Georgia Performance Standards)

Course	Vector Graphics Topics
Accelerated Mathematics 3 (Grades 9, 10, 11, 12) (To be applied at Grade 11 under Math Course Sequence Options 2 & 3)	Understanding and using vectors (algebraic and geometric representations of vectors; conversion between vectors expressed using rectangular coordinates and vectors expressed using magnitude and direction; addition and subtraction of vectors and computation of scalar multiples of vectors; use of vectors to solve realistic problems) (**MA3A10**)

Mathematics

Table 2K (Data Analysis, Probabilities & Statistics Topics):

- Similar to Table 2D, for the particular subject of statics, the relevance of Performance Standards listed in this table are generic and marginal; and this is equally true for many other engineering foundation subjects (p. 35).

Table 2K
Grades 9-12 Data Analysis, Probabilities & Statistics Topics Completion Chart
(According to Georgia Performance standards)

Course	Data Analysis, Probabilities & Statistics Topics
Accelerated Mathematics 1 (Grades 9, 10, 11, 12) (To be applied at Grade 9 under Math Course Sequence Options 2 & 3)	○ Number of outcomes related to a given event. (addition and multiplication principles of counting, simple permutations and combinations) (MA1D1) ○ Basic laws of probability (mutually exclusive events; dependent events. conditional probabilities; predicting outcomes) (MA1D2) ○ Relating samples to a population (MA1D3) ○ Variability of data and mean absolute deviation (MA1D4) ○ Determine an algebraic model to quantify the association between two quantitative variables (gathering and plotting data that can be modeled with linear and quadratic functions; curve fitting; processes of linear and quadratic regression) (MA1D5)
Accelerated Mathematics 2 (Grades 9, 10, 11, 12) (To be applied at Grade 10 under Math Course Sequence Options 2 & 3)	○ Using sample data to make informal inferences about population means and standard deviations (MA2D1) ○ Create probability histograms of discrete random variables, using both experimental and theoretical probabilities (MA2D2) ○ Solve problems involving probabilities by interpreting a normal distribution as a probability histogram for a continuous random variable (z-scores are used for a general normal distribution) (MA2D3) ○ Understand the differences between experimental and observational studies by posing questions and collecting, analyzing, and interpreting data (MA2D4)
Accelerated Mathematics 3 (Grades 9, 10, 11, 12) (To be applied at Grade 11 under Math Course Sequence Options 2 & 3)	○ The central limit theorem. (MA3D1) ○ Margin of error and confidence interval for a specified level of confidence. (MA3D2) ○ Using confidence intervals and margins of error to make inferences from data about a population. (MA3D3)

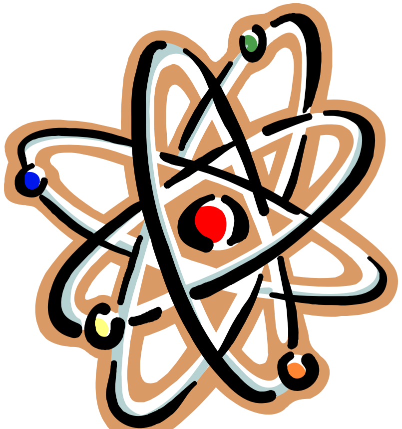
Physics

Georgia Performance Standards mandates **various physics-related content knowledge and problem-solving skills for all grade levels.**

The hard core of physics education is implemented at Grades 9-12.

The most important concepts and principles of physics that are pre-requisites for the infusion of engineering analytic content knowledge into K-12 curriculum:

- **Force,**
- **Energy,**
- **Rate, and**
- **Work.**



Physics

- Table 3A (Physics-Related Science Topics):
- Covered in Grades K-8, and classified as "Science" in the Georgia Standards.org website;
- Each standard is written for one particular grade.
- Generally speaking, these standards provide sufficient amount of preparation for the infusion of engineering analytic and predictive principles at 9th Grade.

Table 3A
Grades K-8 Physics-Related Science Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Physics-Related Science Topics
K	◦ Different types of motion (straight, zigzag, round and round, back and forth, fast and slow, and motionless) (SKP2) → [motion] ◦ Effects of gravity on objects. (SKP3) → [gravity]
1	◦ Weather data and patterns in weather and climate (freezing, melting, precipitation, vaporization) (S1E1) ◦ Changes in water as it relates to weather. (S1E2) → [state of matter] ◦ Light and sound. (S1P1) → [light and sound] ◦ Magnets and effects (S1P2) → [natural phenomenon]
2	◦ Sources and usage of energy (light, heat, and motion) (S2P2) → [energy] ◦ Changes in speed and direction using pushes and pulls. (S2P3) → [motion]
3	◦ Production of heat and the effects of heating and cooling, and understanding a change in temperature indicates a change in heat (S3P1) → [heat] ◦ Magnets and how they affect other magnets and common objects. (S3P2) → [magnetism]
4	◦ Nature of light (mirrors, lenses, prisms) (S4P1) → [light] ◦ Production of sound, vibration of objects and variation of sound by changing the rate of vibration. (S4P2) → [sound] ◦ Relationship between the application of a force and the resulting change in position and motion on an object (simple machines and their uses: lever, pulley, wedge, inclined plane, screw, wheel and axle. Using different size objects, observe how force affects speed and motion. Explaining what happens to the speed or direction of an object when a greater force than the initial one is applied. Effect of gravitational force on the motion of an object (S4P3) → [simple machines and motion]
5	◦ Electricity, magnetism and their relationship. (S5P3) → [electromagnetism]
6	◦ Various sources of energy, their uses, and conservation (the role of the sun as the major source of energy and the sun's relationship to wind and water energy, renewable and nonrenewable resources) (S6E6) → [energy] ◦ Evolutions of current scientific views of the universe (progression of basic historical scientific theories from geocentric to heliocentric, the Big Bang; the position of the solar system in the Milky Way galaxy and the universe; size, surface and atmospheric features of the planets, their relative distance from the sun and ability to support life; motion of objects in the day/night sky in terms of relative position; gravity as the force that governs the motion in the solar system; characteristics of comets, asteroids, and meteors) (S6E1) → [astronomy and universe]
8	◦ Forms and transformations of energy (Law of Conservation of Energy; relationship between potential and kinetic energy; characteristics of heat, light, electricity, mechanical motion, sound; conduction, radiation and convection) (S8P2) ◦ Relationship between force, mass, and the motion of objects (velocity and acceleration; effect of balanced and unbalanced forces on an object in terms of gravity; inertia, and friction; effect of simple machines such as lever, inclined plane, pulley, wedge, screw, and wheel and axle on work) (S8P3) ◦ The wave nature of sound and electromagnetic radiation (characteristics of electromagnetic and mechanical waves; reflection, refraction diffraction, and absorption; how the human eye sees objects and colors in terms of wavelengths, how the behavior of waves is affected by medium such as air, water, solids; amplitude and pitch) (S8P4) ◦ Characteristics of gravity, electricity, and magnetism as major kinds of forces acting in nature (universal gravitational force, mass of and distance between the objects; advantages and disadvantages of series and parallel circuits and transfer of energy; electric currents, magnets and force) (S8P5)

Physics

Table 3B (Physics Topics):

- High school pre-calculus-level physics covered at Grades 9-12;
- Are written not for a particular grade, but for a range of grades (Grades 9-12).
- Offer students solid preparation for university undergraduate level calculus-based physics courses in various engineering programs.
- For high school appropriate engineering curriculum, the relevance of high school physics courses topics varies, depending on the particular engineering foundation subject (for the subject of statics, Newton's Laws are the only pre-requisites needed).
- At Clarke Central High School near the University of Georgia, physics courses are offered at Grade 9, 11, and 12.

Table 3B
Grades 9-12 Physics Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Physics Topics
9-12	**Motion and Force:** o Relationships between force, mass, gravity, and the motion of objects (average and instantaneous velocity; acceleration in a given frame of reference; scalar and vector quantities; comparing graphically and algebraically the relationships among position, velocity, acceleration, and time; magnitude of frictional forces and Newton's three Laws of Motion; magnitude of gravitational forces; measuring and calculating two-dimensional motion, i.e., projectile and circular, with component vectors; centripetal force; conditions required to maintain a body in a state of static equilibrium.) (SP1) o Relationships among force, mass, and motion (velocity and acceleration; applying Newton's three laws to everyday situations by explaining the inertia, relationship between force, mass and acceleration, equal and opposite forces; relating falling objects to gravitational force; difference in mass and weight; calculating amounts of work and mechanical advantage using simple machines) (SPS8) **Energy:** o Evaluating the significance of energy in understanding the structure of matter and the universe (relating the energy produced through fission and fusion by stars as a driving force in the universe; explaining how the instability of radioactive isotopes results in spontaneous nuclear reactions) (SP2) o Evaluating the forms and transformations of energy (principle of conservation of energy, components of work-energy theorem and total energy in a closed system; different types of potential energy; o kinetic energy; transformations between potential and kinetic energy; relationship between matter and energy; vector nature of momentum; elastic and inelastic collisions; factors required to produce a change in momentum; relationship between temperature, internal energy, and work done in a physical system; power) (SP3) o Relating transformations and flow of energy within a system (energy transformations within a system; molecular motion as it relates to thermal energy changes in terms of conduction, convection, and radiation; determining the heat capacity of a substance using mass, specific heat, and temperature; explaining the flow of energy in phase changes through the use of a phase diagram) (SPS7) **Electro-magnetic waves:** o Properties of waves (all waves transferring energy; relating frequency and wavelength to the energy of different types of electromagnetic waves and mechanical waves; characteristics of electromagnetic and mechanical or sound waves; phenomena of reflection, refraction, interference, and diffraction; relating the speed of sound to different mediums; Doppler Effect (SPS9) o Properties and applications of waves (processes that results in the production and energy transfer of electromagnetic waves; behavior of waves in various media in terms of reflection, refraction, and diffraction of waves; relationship between the phenomena of interference and the principle of superposition; transfer of energy through different mediums by mechanical waves; location and nature of images formed by the reflection or refraction of light) (SP4) o Relationships between electrical and magnetic forces (transformation of mechanical energy into electrical energy and the transmission of electrical energy; relationship among potential difference, current, and resistance in a direct current circuit; equivalent resistances in series and parallel circuits; relationship between moving electric charges and magnetic fields) (SP5) o Properties of electricity and magnetism (static electricity in terms of Friction, induction, conduction; alternating and direct current; voltage, resistance and current; simple series and parallel circuits; movement of electrical charge as it relates to electromagnets, simple motors, permanent magnets) (SPS10)
9-12	**Relativity & Modern Physics:** o Corrections to Newtonian physics given by quantum mechanics and relativity when matter is very small, moving fast compared to the speed of light, or very large (matter as a particle and as a wave; the Uncertainty Principle; differences in time, space, and mass measurements by two observers when one is in a frame of reference moving at constant velocity parallel to one of the coordinate axes of the other observer's frame of reference if the constant velocity is greater than one tenth the speed of light; gravitational field surrounding a large mass and its effect on a ray of light) (SP6) o Characteristics and components of radioactivity (alpha and beta particles and gamma radiation; fission and fusion; half-life and radioactive decay; nuclear energy as an alternative energy source, and its potential problems) (SPS3) o Phases of matter as they relate to atomic and molecular motion (atomic/molecular motion of solids, liquids, gases and plasmas; relating temperature, pressure, and volume of gases to the behavior of gases) (SPS5)

Chemistry

Important chemistry content knowledge needed as pre-requisites for engineering curriculum:

1. **Atomic structure;**
2. **Properties of matters;**
3. **The Periodic Table;**
4. **The Law of Conservation of Matter;**
5. **Chemical reactions; and**
6. **Chemical energy and its conversion into other forms of energy.**

Preparation in chemistry is

- **For material science:** Very important.
- **For fluid mechanics, heat transfer and thermodynamics:** Fairly important.
- **For statics and dynamics:** Relevance is marginal. → **Georgia Performance Standards for Chemistry is not used in the selection of high school appropriate statics topics.**

Georgia Performance Standards mandates various chemistry-related content knowledge and problem-solving skills for all grade levels. **The hard core of chemistry education is implemented at Grades 9-12.**

Chemistry

Table 4A (Chemistry and Materials-Related Topics):

- For Grades K-8, listed under the generic "Science" category.
- Written for particular grade levels.
- Generally provides some basic cognitive background in the 6 important areas of pre-requisite chemistry content knowledge listed in the previous slide.

Table 4A
Grades K-8 Chemistry & Materials Related Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Chemistry & Materials Related Topics
K	◦ Physical attributes of rocks and soils (SKE2) → [properties of materials] ◦ Physical properties (clay, cloth, paper, plastic, etc.); physical attributes (color, size, shape, weight, texture, buoyancy, flexibility) (SKP1) → [physical properties and attributes]
2	Properties of matter and changes that occur in objects (the three common states of matter as solid, liquid, or gas; changes in objects by tearing, dissolving, melting, squeezing, etc.) (S2P1) → [states of matter]
4	States of water and how they relate to the water cycle and weather (temperatures at which water becomes a solid or a gas, etc.) (S4E3) → [states of water]
5	◦ Difference between a physical change (separating mixtures, cutting, tearing, folding paper) and a chemical change (chemical reaction) (S5P2) → [chemical and physical changes]
6	◦ Significant role of water in earth processes (oceans, rivers, lakes, underground water, and ice; various atmospheric conditions and stages of the water cycle; composition, location, and subsurface topography of the world's oceans; causes of waves, currents, and tides) (S6E3) → [role of water] ◦ The way the distribution of land and oceans affects climate and weather (land and water absorbing and losing heat at different rates; unequal heating of land and water surfaces to form large global wind systems and weather events such as tornados and thunderstorms; moisture evaporating from the oceans affecting weather patterns and weather events such as hurricanes) (S6E4) → [weather pattern] ◦ Formation of the earth's surface (temperature, density, and composition of the Earth's crust, mantle, and core; composition of rocks in terms of minerals; classification of rocks by their process of formation; -movement of lithospheric plates and major geological events on the earth's surface; effects of physical processes such as plate tectonics, erosion, deposition, volcanic eruption, gravity on geological features including oceans such as composition, currents, and tides; soil as consisting of weathered rocks and decomposed organic material; effects of human activity on the erosion of the earth's surface; conserving natural resources (S6E5) → [formation of the Earth's surface]
8	◦ Scientific view of the nature of matter (atoms and molecules; pure substances and mixtures; movement of particles in solids, liquids, gases, and plasma states; physical properties such as density, melting point, boiling point; and chemical properties such as reactivity, combustibility; change in chemical properties such as development of a gas, formation of precipitate, and change in color; Periodic Table of Elements; the Law of Conservation of Matter) (S8P1) → [nature of matter]

Chemistry

Table 4B (Chemistry Topics):

- Hard core chemistry courses offered to high school students (Grades 9-12);
- Georgia Performance Standards for Chemistry established as a single sub-category under the general category of "Science;"
- Written for a range of grades (Grades 9, 10, 11, and 12). They provide a solid preparation for college undergraduate engineering programs.

Table 4B
Grades 9-12 Chemistry Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Chemistry Topics
9-12	**Classified as "Physics:"** o Nature of matter, its classifications, and the system for naming types of matter (density; formulas for stable binary ionic compounds based on balance of charges; using IUPAC nomenclature for transition between chemical names and chemical formulas of binary ionic compounds; binary covalent compounds; the Law of Conservation of Matter in a chemical reaction; balancing chemical equations for synthesis, decomposition, single replacement, double replacement) (SPS2) → [nature of matter] o Arrangement of the Periodic Table (trends of the number of valence electrons, types of ions formed by representative elements, location of metals, nonmetals, and metalloids; phases at room temperature) (SPS4) → [periodic table] o Properties of solutions (solute/solvent, conductivity, concentration; factors affecting the rate a solute dissolves in a specific solvent; solubility curve; components and properties of acids and bases; determining whether common household substances are acidic, basic, or neutral) (SPS6) → properties of solutions] **Classified as "Chemistry:"** o Nature of matter and its classifications. Role of nuclear fusion in producing essentially all elements heavier than hydrogen; identifying substances based on chemical and physical properties; predicting formulas for stable ionic compounds - binary and tertiary - based on balance of charges; using IUPAC nomenclature for both chemical names and formulas: Ionic compounds (Binary and tertiary), Covalent compounds (Binary and tertiary); acidic compounds (Binary and tertiary) (SC1) → [nature of matter] o The Law of Conservation of Matter and its use to determine chemical composition in compounds and chemical reactions (identifying and balancing chemical equations: Synthesis, Decomposition, Single Replacement, Double Replacement, Combustion. Experimentally determining indicators of a chemical reaction specifically precipitation, gas evolution, water production, and changes in energy to the system. Applying concepts of the mole and Avogadro's number to conceptualize and calculate; empirical/molecular formulas; mass, moles and molecules relationships; molar volumes of gases; different types of stoichiometry problems; conceptual principle of limiting reactants; role of equilibrium in chemical reactions) (SC2) → [the law of conservation of matter] o Using the modern atomic theory to explain the characteristics of atoms (SC3) → modern atomic theory] o Using the organization of the Periodic Table to predict properties of elements. (SC4) → [periodic table] o Understanding that the rate at which a chemical reaction occurs can be affected by changing concentration, temperature, or pressure and the addition of a catalyst. (SC5) → rate of chemical reaction] o Understanding the effects of motion of atoms and molecules in chemical and physical processes (atomic/molecular motion in solids, liquids, gases, and plasmas; amount of heat given off or taken in by chemical or physical processes; flow of energy during change of state or phase) (SC6) → [atomic/molecule motion] o Properties that describe solutions and the nature of acids and bases (process of dissolving in terms of solute/solvent interactions: such as factors that effect the rate at which a solute dissolves in a specific solvent; concentrations as molarities; preparing and properly labeling solutions of specified molar concentration; relating molality to colligative properties. Compare, contrast, and evaluate the nature of acids and bases: Arrhenius, Bronsted-Lowry Acid/Bases, strong vs. weak acids/bases in terms of percent dissociation; Hydronium ion concentration; pH; acid-base neutralization) (SC7) → [acids and bases]

Environmental Science

- Georgia Performance Standards for Science at Grade 3 and Grade 5 mandate coverage of important knowledge about **pollution, conservation of natural resources and recycling**. → Important factors for **socially responsible and ecologically sustainable engineering design**. → Should be incorporated as factors for the development of K-12 appropriate engineering curriculum, whenever applicable (notably in the subject of **material science**).

Table 5
Grades 3 and 5 Environment Science Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Environment Science Topics
3	◦ Effects of pollution and humans on the environment, protection of environment, conservation of resources, recycling of materials (S3L2) → [pollution, conservation and recycling]
5	◦ Identifying surface features of the Earth caused by constructive processes (deposition, earthquakes, volcanoes, faults) and destructive processes (erosion, weathering, impact of organisms, earthquake, volcano), and role of technology and human intervention in the control of constructive and destructive processes (seismological studies, flood control, beach reclamation) (S5E1) → [constructive and destructive processes]

General Scientific Approach

- At Grade 7, under the category of "Science," Georgia Performance Standards mandate sufficient amount of generic knowledge and skills related to the **process of scientific inquiry, experimentation, and discovery,** which are sufficient for students to develop appropriate **methodology in engineering study and practice**, which is applicable in both **high school and college-level engineering curriculum**.

Table 6
Grade 7 General Scientific Approach Topics Completion Chart
(According to Georgia Performance Standards)

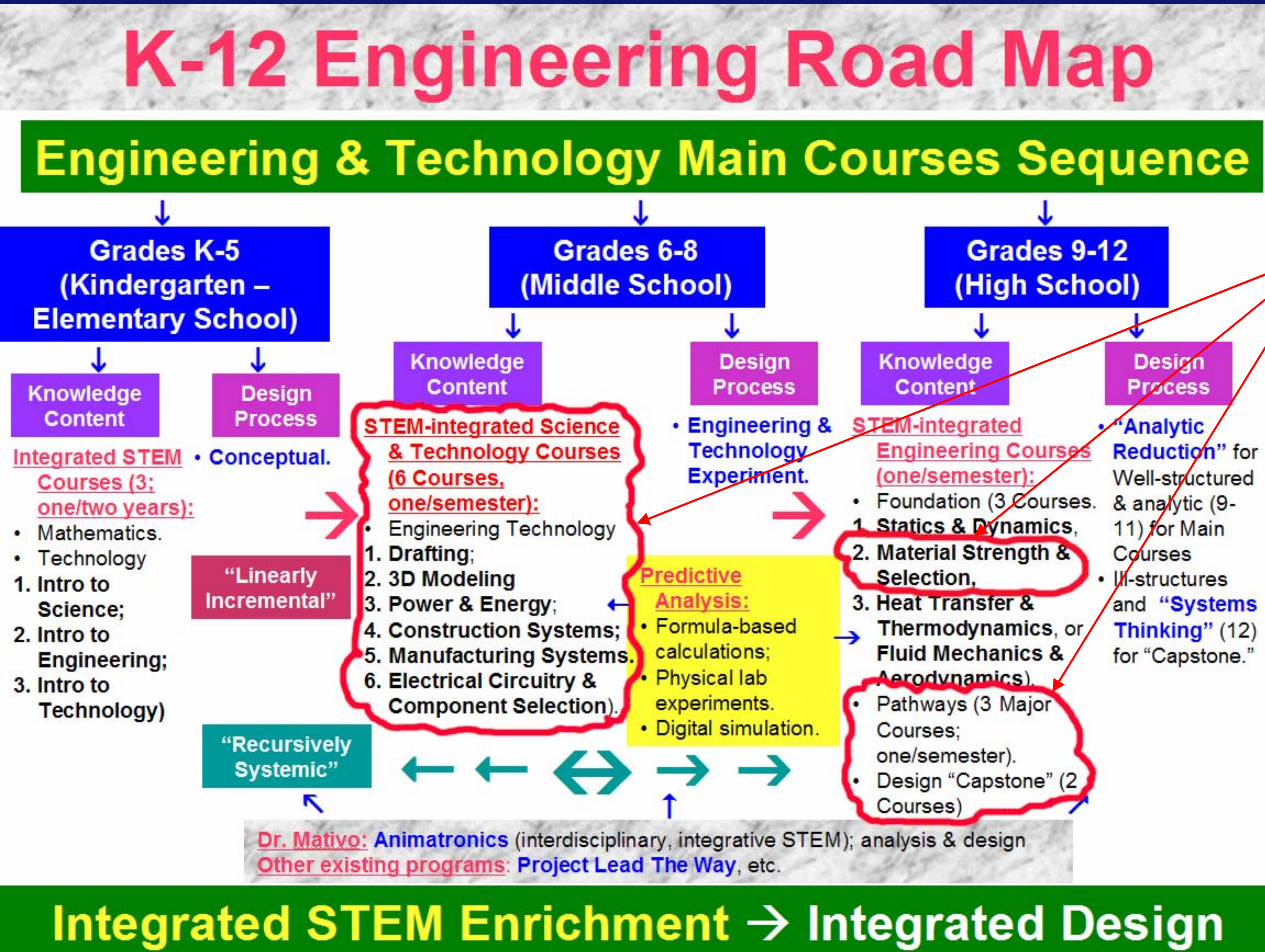
Grade	General Scientific Approach Topics
7	◦ Exploring the importance of curiosity, honesty, openness, and skepticism in science; exhibiting these traits in to understand how the world works (understanding the importance of, and keeping honest, clear, and accurate records in science; understanding that hypotheses can be valuable, even if they turn out not to be completely accurate) (S7CS1) ◦ Using tools and instruments for observing, measuring, and manipulating equipment and materials in scientific activities (using appropriate technology to store and retrieve scientific information in topical, alphabetical, numerical, and keyword files, and create simple files; measuring objects and/or substances; standard safety practices for scientific investigations) (S7CS4) ◦ Using the ideas of system, model, change, and scale in exploring scientific and technological matters (observing and explaining how parts can be related to other parts in a system such as predator/prey relationships in a community/ecosystem; understanding that different models such as physical replicas, pictures, and analogies, can be used to represent the same thing) (S7CS5) ◦ Communicating scientific ideas and activities clearly (writing clear, step-by-step instructions for conducting particular scientific investigations, operating a piece of equipment, or following a procedure; writing for scientific purposes incorporating data from circle, bar, and line graphs, two-way data tables, diagrams, and symbols; organizing scientific information using appropriate simple tables, charts, and graphs, and identify relationships they reveal) (S7CS6) ◦ Questioning scientific claims and arguments effectively (questioning claims based on vague attributions such as "Leading doctors say..." or on statements made by people outside the area of their particular expertise; identifying the flaws of reasoning that are based on poorly designed research, i.e., facts intermingled with opinion, conclusions based on insufficient evidence; questioning the value of arguments based on small samples of data, biased samples, or samples for which there was no control; recognizing that there may be more than one way to interpret a given set of findings) (S7CS7) ◦ Investigating the characteristics of scientific knowledge and how that knowledge is achieved (when similar investigations give different results, the scientific challenge is to judge whether the differences are trivial or significant, which often requires further study; even with similar results, scientists may wait until an investigation has been repeated many times before accepting the results as meaningful; when new experimental results are inconsistent with an existing, well established theory, scientists may pursue further experimentation to determine whether the results are flawed or the theory requires modification; as prevailing theories are challenged by new information, scientific knowledge may change) (S7CS8)
7	◦ Investigating the features of the process of scientific inquiry (investigations are conducted for different reasons, which include exploring new phenomena, confirming previous results, testing how well a theory predicts, and comparing competing theories; scientific investigations usually involve collecting evidence, reasoning, devising hypotheses, and formulating explanations to make sense of collected evidence; scientific experiments investigate the effect of one variable on another. All other variables are kept constant; scientists often collaborate to design research. To prevent bias, scientists conduct independent studies of the same questions; accurate record keeping, data sharing, and replication of results are essential for maintaining an investigator's credibility with other scientists and society; scientists use technology and mathematics to enhance the process of scientific inquiry; the ethics of science require that special care must be taken and used for human subjects and animals in scientific research. Scientists must adhere to the appropriate rules and guidelines when conducting research) (S7CS9)

Engineering and Technology

- The Engineering and Technology program “combines hands-on projects with a rigorous curriculum to prepare students for the most challenging postsecondary engineering and technology programs. […] build solid writing, comprehension, calculation, problem-solving, and technical skills;” and that it encourages students to “take relevant math and science courses, such as advanced algebra, chemistry, calculus, geometry, trigonometry, physics, design, and engineering concepts.”

https://www.georgiastandards.org/Standards/Pp./BrowseStandards/ctae-engineering.aspx.

Mutual Compatibility
(Georgia Performance Standards for Engineering and Technology and the Proposed Model of Infusing Engineering Design into K-12 Curriculum)



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Mutual Compatibility Chart

Subject (Course) under GPS for Engineering & Technology	Compatibility with Engineering & Technology Main Course Sequence on the K-12 Engineering Road Map under the Proposed Model				
	Grades K-5 (Kindergarten to Elementary School)	Grades 6-8 (Middle School)	Grades 9-12 (High School)		
	Technology Course (Grades K-5)	Engineering Technology Course (Grades 6-8)	Foundation (Grades 9-10)	Pathway Course (Grades 10-11)	Design "Capstone" Option (Grade 12)
Electronics					
Foundations of Electronics		Electrical Circuitry and Component Selection		Electronics (Grade 10)	
Advanced AC and DC Circuits				Electronics Grade 11)	
Digital Electronics				Electronics (Grade 11)	
Electronics Internship					Electronics (Grade 12)
Energy Systems					
Foundations of Engineering and Technology	• Intro to Science • Intro to Engineering • Intro to Technology				
Energy and Power Technology		Power & Energy			
Appropriate and Alternative Energy Technologies		Power & Energy			
Energy Systems Internship					Energy
Engineering					
Foundations of Engineering and Technology	• Intro to Science • Intro to Engineering • Intro to Technology				
Engineering Concepts					All Options (Grade 12)
Engineering Applications					All Options (Grade 12)
Engineering Internship					All Options (Grade 12)

Existing Courses under Georgia Performance Standards

Courses under the Proposed Model for Infusing Engineering Design into K-12 Curriculum

Subject (Course) under GPS for Engineering & Technology	Compatibility with Engineering & Technology Main Course Sequence on the K-12 Engineering Road Map under the Proposed Model				
	Grades K-5 (Kindergarten to Elementary School)	Grades 6-8 (Middle School)	Grades 9-12 (High School)		
	Technology Course (Grades K-5)	Engineering Technology Course (Grades 6-8)	Foundation (Grades 9-10)	Pathway Course (Grades 10-11)	Design "Capstone" Option (Grade 12)
Engineering, Graphics & Design					
Introduction to Engineering, Drawing & Design		Drafting			
Survey of Engineering Graphics		Drafting			
3-D Modeling Analysis		3D Modeling			
Manufacturing					
Foundations of Manufacturing and Materials Science		Manufacturing Systems	Material Strength & Selection (Grade 9)	Manufacturing (Grade 10)	
Robotics and Automatic Systems				Manufacturing (Grade 10)	
Production Enterprises				Manufacturing (Grade 11)	
Manufacturing Internship					Manufacturing
Other GPS Engineering & Technology Courses					
Research, Design and Project Management					Generic engineering design and management experience

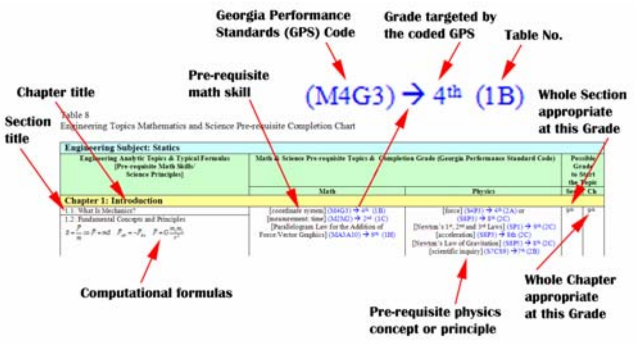
Relevance of Georgia Performance Standards for Engineering and Technology to Infusion of Engineering Analytic Content Knowledge into K-12 Curriculum

Contributions: Great contributions in: (1) "Technology" courses ("Introduction to Science, Engineering and Technology," corresponding to Grades K-5 in the "K-12 Engineering Road Map" shown in *Figure 4D*); (2) "Engineering Technology" courses (for various engineering-related technology courses, corresponding to Grades 6-8); (3) "Pathway" courses (for various options of engineering fields, corresponding to Grades 10-11); and (4) "Design Capstone" courses (for an interdisciplinary design and internship experience at Grade 12). → **A basis for the eventual development of a comprehensive and systematic set of national and state K-12 engineering education performance standards in the above 4 areas.**

Limitations: Generally have no direct relationship with the four high school "Foundation" engineering courses featured in the proposed "K-12 Engineering Road Map:" (1) Statics and Dynamics, (2) Material Strength and Selection (the material strength portion), (3) Heart Transfer and Thermodynamics, (4) Fluid Mechanics and Aerodynamics. → **Will not be used as reference for the selection of high school appropriate foundation engineering analytic principles to be incorporated into the above-mentioned four "Foundation" engineering courses.**

Selecting High School Appropriate

Statics Topics



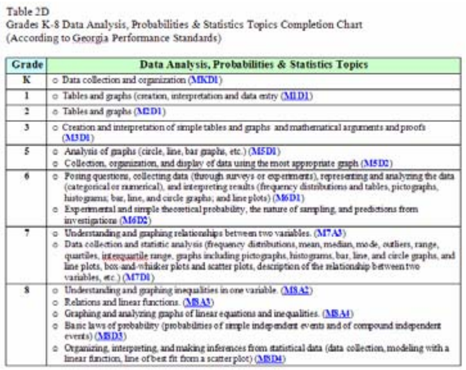
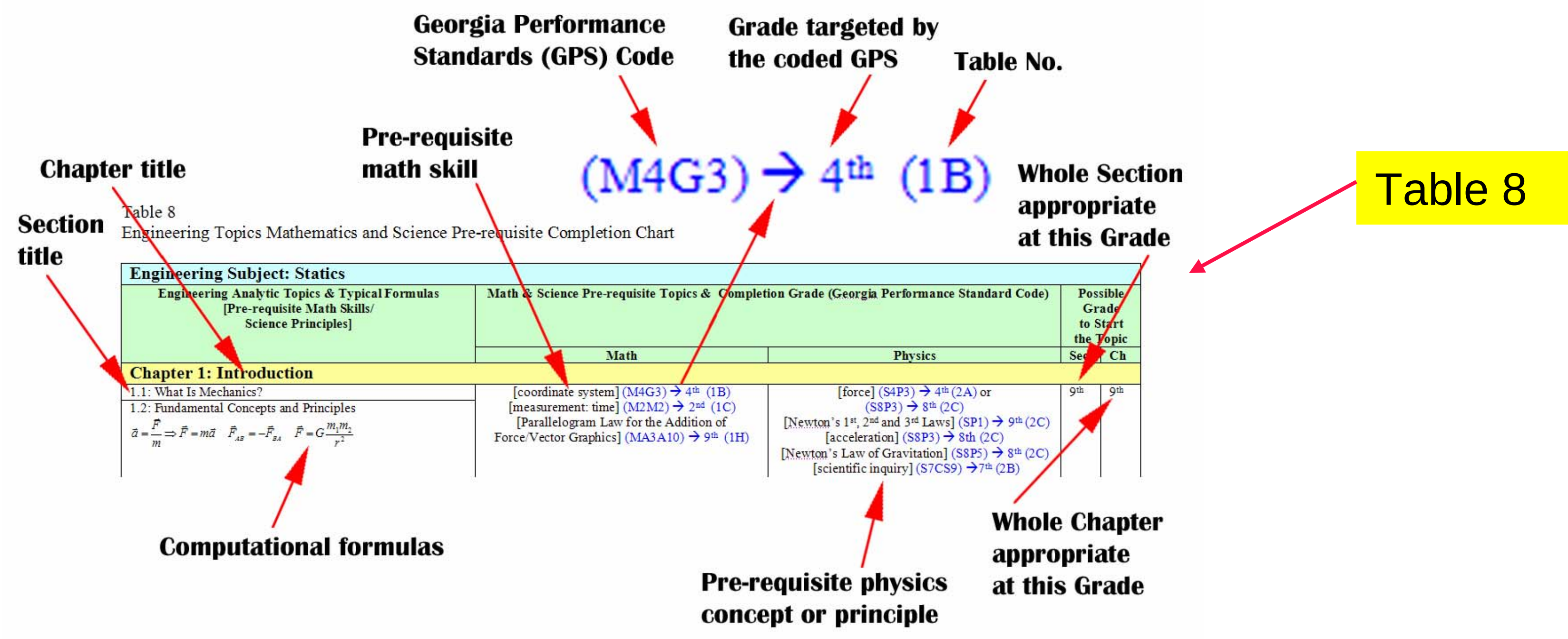


Table 2D
Grades K-8 Data Analysis, Probabilities & Statistics Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Data Analysis, Probabilities & Statistics Topics
K	○ Data collection and organization (MKD1)
1	○ Tables and graphs (creation, interpretation and data entry (M1D1)
2	○ Tables and graphs (M2D1)
3	○ Creation and interpretation of simple tables and graphs and mathematical arguments and proofs (M3D1)
5	○ Analysis of graphs (circle, line, bar graphs, etc.) (M5D1) ○ Collection, organization, and display of data using the most appropriate graph (M5D2)
6	○ Posing questions, collecting data (through surveys or experiments), representing and analyzing the data (categorical or numerical), and interpreting results (frequency distributions and tables, pictographs, histograms; bar, line, and circle graphs; and line plots) (M6D1) ○ Experimental and simple theoretical probability, the nature of sampling, and predictions from investigations (M6D2)
7	○ Understanding and graphing relationships between two variables. (M7A3) ○ Data collection and statistic analysis (frequency distributions, mean, median, mode, outliers, range, quartiles, interquartile range, graphs including pictographs, histograms, bar, line, and circle graphs, and line plots, box-and-whisker plots and scatter plots, description of the relationship between two variables, etc.) (M7D1)
8	○ Understanding and graphing inequalities in one variable. (M8A2) ○ Relations and linear functions. (M8A3) ○ Graphing and analyzing graphs of linear equations and inequalities. (M8A4) ○ Basic laws of probability (probabilities of simple independent events and of compound independent events) (M8D3) ○ Organizing, interpreting, and making inferences from statistical data (data collection, modeling with a linear function, line of best fit from a scatter plot) (M8D4)

Data Analysis & Tabulation: Engineering Topics Mathematics and Science Pre-requisite Completion Chart



- The selected textbook browsed and read page by page.
- All analytic and predictive principles and associated computational formulas tabulated and carefully analyzed to determine the pre-requisite mathematics computational skills and principles of physics needed for K-12 students to comfortably study these statics-related topic at a particular grade level within the K-12 curriculum.

Procedures of Analysis and Selection

1st Step (Defining Mathematics and Physics Pre-requisites): Each mathematics skills and physics concepts or principles have been defined through careful analysis of their computational formulas, and tabulated in the Math and Physics columns of Table 8.

2nd Step (Finding the Earliest Grade of Fulfillment of Mathematics and Physics Pre-requisites): Relevant tables (Tables 2A through 6, pp. 30-47) have been checked to find the earliest grade level where these pre-requisites are required to be explored at a sufficient depth.

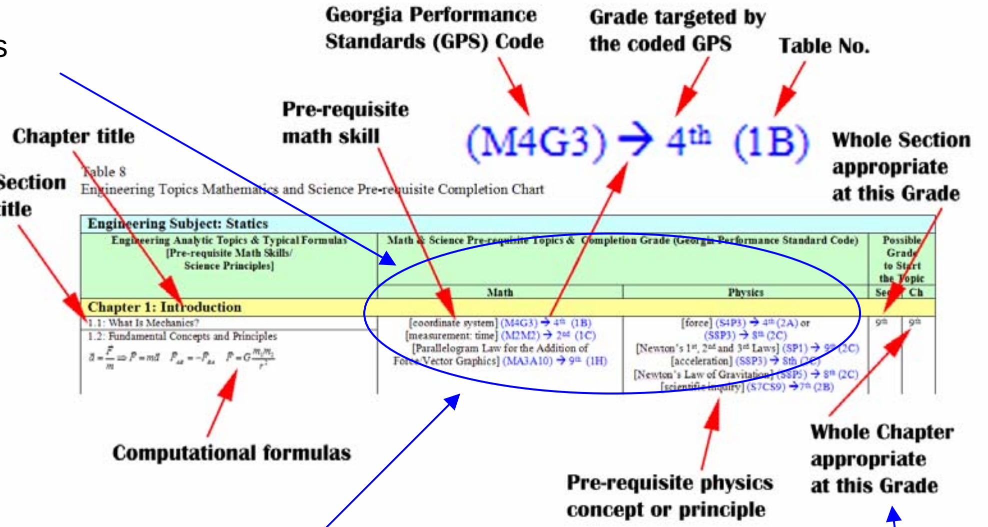


Table 2D
Grades K-8 Data Analysis, Probabilities & Statistics Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Data Analysis, Probabilities & Statistics Topics
K	o Data collection and organization (MKD1)
1	o Tables and graphs (creation, interpretation and data entry (M1D1)
2	o Tables and graphs (M2D1)
3	o Creation and interpretation of simple tables and graphs and mathematical arguments and proofs (M3D1)
5	o Analysis of graphs (circle, line, bar graphs, etc.) (M5D1) o Collection, organization, and display of data using the most appropriate graph (M5D2)
6	o Posing questions, collecting data (through surveys or experiments), representing and analyzing the data (categorical or numerical), and interpreting results (frequency distributions and tables, pictographs, histograms; bar, line, and [illegible] and line plots) (M6D1) o Experimental and simple theoretical pr[illegible]ility, the nature of sampling, and predictions from investigations (M6[illegible]2)
7	o Understanding a[illegible]d graphing relationships be[illegible]en two variables. (M7A3) o Data collection [illegible]nd statistic analysis (frequen[illegible]istributions, mean, median, mode, outliers, range, quartiles, inter[illegible]artile range, graphs including [illegible]ographs, histograms, bar, line, and circle graphs, and line plots, box-[illegible]nd-whisker plots and scatter pl[illegible] description of the relationship between two variables, etc.) ([illegible]7D1)
8	o Understanding a[illegible]d graphing inequalities in o[illegible]ariable. (M8A2) o Relations and line[illegible] functions. (M8A3) o Graphing and ana[illegible] graphs of linea[illegible]ations and inequalities. (M8A4) o Basic laws of [illegible]bility [illegible] of simple independent events and of compound independent events) (M[illegible] o Organizi[illegible]preting, and making inferences from statistical data (data collection, modeling with a linear[illegible], line of best fit from a scatter plot) (M8D4)

3rd Step (Recording the Earliest Grade of Fulfillment of Each Mathematics and Physics Pre-requisite): The Georgia Performance Standards Code is listed together with its Grade level and the number of table (i.e., the location where the Georgia Performance Standards Code could be found.

4th Step (Determining the Appropriate Grade for Infusing Each Topic of Statics by Finding the Grade of Fulfillment of All Mathematics and Physics Pre-requisites): All of the items listed under the same section (or several sections sharing similar pre-requisites) are compared to find the latest Grade level, which is selected as the appropriate Grade level for the section(s), and entered in the "Sec" (or "Section") sub-column under the "Possible Grade to Start the Topic" column. After all Sections under the same Chapter are processed in the same way, the grade levels for various Sections entered in the "Sec" sub-column are compared; and the latest grade level is selected as the appropriate grade level to start teaching K-12 students the relevant statics-related engineering analytic and predictive principles and skills; and the Grade code is entered in the "Ch" (meaning "Chapter") sub-column.

Procedures of Analysis and Selection

1st Step (Defining Mathematics and Physics Pre-requisites): Math and physics pre-requisites have been defined through careful analysis of their computational formulas, and tabulated in the Math and Physics columns of Table 8.

Math:

[Four Operations]

$$\vec{P} \equiv \frac{\vec{F}}{A}$$

Physics:

[Force]

$$\vec{P}$$

$$\vec{F}$$

$$\vec{F} \equiv m\vec{a}$$

Georgia Performance Standards (GPS) Code

Grade targeted by the coded GPS

Table No.

Pre-requisite math skill

Chapter title

Section title

(M4G3) → 4th (1B)

Whole Section appropriate at this Grade

Table 8

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?	[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
1.2: Fundamental Concepts and Principles $\vec{a} = \frac{\vec{F}}{m} \Rightarrow \vec{F} = m\vec{a}$ $\vec{F}_{AB} = -\vec{F}_{BA}$ $\vec{F} = G\frac{m_1 m_2}{r^2}$				

Computational formulas

Pre-requisite physics concept or principle

Whole Chapter appropriate at this Grade

2nd Step (Finding the Earliest Grade of Fulfillment of Mathematics and Physics Pre-requisites): Relevant tables (Tables 2A through 6, pp. 30-47) have been checked to find the earliest grade level where these pre-requisites are required to be explored at a sufficient depth.

Table 2G

Grades 9-12 Linear Algebra Topics Completion Chart

(According to Georgia Performance Standards)

Course	Linear Algebra Topics
Accelerated Mathematics 2 (Grades 9, 10, 11, 12) (To be applied at Grade 10 under Math Course Sequence Options 2 & 3)	o Basic operations with matrices (adding, subtracting, multiplyin[illegible] and inverting [illegible]o-by-two and larger matrices) (MA2A6) o Using matrices to formulate and solve problems (represe[illegible] a system of linear equations as a matrix equation; solve matrix equations using inv[illegible]atrices, represent and solve realistic problems using systems of linear equations) [illegible]2A7) o Solving linear programming problems in two vari[illegible] (solve systems of inequalities in two variables, showing the solutions graphically; re[illegible]t and solve realistic problems using linear programming) (MA2A8) o Matrix representations of vertex-edge graphs (MA2A9)

Procedures of Analysis and Selection

3rd Step (Recording the Earliest Grade of Fulfillment of Each Mathematics and Physics Pre-requisite): The GPS Code is listed together with its Grade level and the number of table (i.e., the location where the Code could be found.

Georgia Performance Standards (GPS) Code

Grade targeted by the coded GPS

Table No.

Pre-requisite math skill

(M4G3) → 4^{th} (1B)

Chapter title

Section title

Whole Section appropriate at this Grade

Table 8

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? …: Fundamental Concepts and Principles $\vec{F}=m\vec{a}$ $\vec{F}_{AB}=-\vec{F}_{BA}$ $\vec{F}=G\frac{m_1m_2}{r^2}$	[coordinate system] (M4G3) → 4^{th} (1B) [measurement: time] (M2M2) → 2^{nd} (1C) [Parallelogram Law for the Addition of Force/Vector Graphics] (MA3A10) → 9^{th} (1H)	[force] (S4P3) → 4^{th} (2A) or (S8P3) → 8^{th} (2C) [Newton's 1^{st}, 2^{nd} and 3^{rd} Laws] (SP1) → 9^{th} (2C) [acceleration] (S8P3) → 8th (2C) [Newton's Law of Gravitation] (S8P5) → 8^{th} (2C) [scientific inquiry] (S7CS9) → 7^{th} (2B)	9^{th}	9^{th}

Computational formulas

Pre-requisite physics concept or principle

Whole Chapter appropriate at this Grade

4th Step (Determining the Appropriate Grade for Infusing Each Topic of Statics by Finding the Grade of Fulfillment of All Mathematics and Physics Pre-requisites): All of the items listed under the same section (or several sections sharing similar pre-requisites) are compared to find the latest Grade level, which is selected as the appropriate Grade level for the section(s), and entered in the "Sec" (or "Section") sub-column under the "Possible Grade to Start the Topic" column. After all Sections under the same Chapter are processed in the same way, the grade levels for various Sections entered in the "Sec" sub-column are compared; and the latest grade level is selected as the appropriate grade level to start teaching K-12 students the relevant statics-related engineering analytic and predictive principles and skills; and the Grade code is entered in the "Ch" (meaning "Chapter") sub-column.

Applying the Selection

- **Options 2 and 3:** The determination of the appropriate grade level to start any particular statics-related engineering analytic topic is based on the Options 2 and Option 3 of middle and high school Math Course Sequence, which are established for average performing students.

- **Option 4:** For students enrolled in the Options 4 Math Course Sequence, such determination will still apply.

- **Option 5:** For mathematically "highly-talented" students enrolled in the Options 5 Math Course Sequence, such determination could be adjusted in terms of allowing students to enroll in the K-12 appropriate statics course at one earlier grade before the grade determined for all other Options.

Adjustment for Mathematically "Highly-Talented" Students

Whole Section appropriate at this Grade

Performance Standard Code)	Possible Grade to Start the Topic	
Physics	Sec	Ch
S4P3) → 4th (2A) or P3) → 8th (2C) and 3rd Laws] (SP1) → 9th (2C) on] (S8P3) → 8th (2C) Gravitation] (S8P5) → 8th (2C) quiry] (S7CS9) →7th (2B)	9th	9th

Whole Chapter appropriate at this Grade

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Georgia Department of Education
Secondary Mathematics
Guidance for Course Sequences under the Georgia Performance Standards

Georgia Performance Standards (GPS) Math Course Sequence					
	Option 1	Option 2	Option 3	Option 4	Option 5
Grade			Advanced	Accelerated	Accelerated
6th	6th Grade GPS	6th Grade GPS	6th Grade Advanced GPS	6th, 7th, and 8th grade GPS	6th, 7th, and 8th grade GPS
7th	7th Grade GPS	7th Grade GPS	7th Grade Advanced GPS		
8th	8th Grade GPS	8th Grade GPS	8th Grade Advanced GPS	Math 1	Accelerated Math 1
9th	Math 1	Accelerated Math 1	Accelerated Math 1	Math 2	Accelerated Math 2
10th	Math 2	Accelerated Math 2	Accelerated Math 2	Math 3	Accelerated Math 3
11th	Math 3	Accelerated Math 3	Accelerated Math 3	Math 4	AP Statistics*; AP Calculus AB/BC; Joint Enrollment
12th	Math 4; AP Statistics*; Discrete Math	AP Calculus AB/BC; AP Statistics*; Discrete Math; Joint Enrollment	AP Calculus AB/BC; AP Statistics*; Discrete Math; Joint Enrollment	AP Calculus AB; AP Statistics*; Discrete Math; Joint Enrollment	AP Statistics*; AP Calculus AB/BC; Joint Enrollment

*AP Statistics may be taken concurrently with an upper level math course at the system's discretion.

Structural Incorporation of Engineering Topics into K-12 Engineering Curriculum

Topics of statics include:

1. Those based on **pre-calculus** mathematics, and
2. Those based on **calculus** mathematics.

- The **Math Course Sequence** developed under Georgia Performance Standards for Mathematics is used as a reference for the exploration of strategies to infuse both components into K-12 curriculum.

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Georgia Department of Education
Secondary Mathematics
Guidance for Course Sequences under the Georgia Performance Standards

Georgia Performance Standards (GPS) Math Course Sequence

Grade	Option 1	Option 2	Option 3 Advanced	Option 4 Accelerated	Option 5 Accelerated
6th	6th Grade GPS	6th Grade GPS	6th Grade Advanced GPS	6th, 7th, and 8th grade GPS	6th, 7th, and 8th grade GPS
7th	7th Grade GPS	7th Grade GPS	7th Grade Advanced GPS		
8th	8th Grade GPS	8th Grade GPS	8th Grade Advanced GPS	Math 1	Accelerated Math 1
9th	Math 1	Accelerated Math 1	Accelerated Math 1	Math 2	Accelerated Math 2
10th	Math 2	Accelerated Math 2	Accelerated Math 2	Math 3	Accelerated Math 3
11th	Math 3	Accelerated Math 3	Accelerated Math 3	Math 4	AP Statistics*; AP Calculus AB/BC; Joint Enrollment
12th	Math 4; AP Statistics*; Discrete Math	AP Calculus AB/BC; AP Statistics*; Discrete Math; Joint Enrollment	AP Calculus AB/BC; AP Statistics*; Discrete Math; Joint Enrollment	AP Calculus AB; AP Statistics*; Discrete Math; Joint Enrollment	AP Statistics*; AP Calculus AB/BC; Joint Enrollment

*AP Statistics may be taken concurrently with an upper level math course at the system's discretion.

Summary of Table 8 (pp. 58-80)

5 Out of all 10 Chapters in the selected college-level statics textbook (Beer et al, 2004) 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.

Table 8
Engineering Topics Mathematics and Science Pre-requisite Completion Chart for the Subject of Statics

Engineering Subject: Statics				
Engineering Analytic Topics & Typical Formulas	**Math & Science Pre-requisite Topics & Completion Grade (Georgia Performance Standard Code)** **[Pre-requisite Math Skills/Science Principles] (GPS Code) → Grade (Table No.)**		**Possible Grade to Start the Topic**	
	Math	**Physics**	**Sec**	**Ch**
Chapter 1: Introduction				
1.1: What Is Mechanics? **1.2: Fundamental Concepts and Principles** $\vec{a} = \frac{\vec{F}}{m} \Rightarrow \vec{F} = m\vec{a}$ $\vec{F}_{AB} = -\vec{F}_{BA}$ $\vec{F} = G\frac{m_1 m_2}{r^2}$	[coordinate system] (M4G3) → 4th (2B) [measurement: time] (M2M2) → 2nd (2C) [Parallelogram Law for the Addition of Force/Vector Graphics] (MA3A10) → 11th (2H) → To be taught as a special math topic	[force] (S4P3) → 4th (3A) or (S8P3) → 8th (3C) [Newton's 1st, 2nd and 3rd Laws] (SP1) → 9th (3C) [acceleration] (S8P3) → 8th (3C) [Newton's Law of Gravitation] (S8P5) → 8th (3C) [scientific inquiry] (S7CS9) → 7th (3B)	9th	9th
1.3: Systems of Units **1.4: Conversion from One System of Units to Another**	[unit conversion] (M6M1) → 6th (2C)	N/A	6th	
1.5: Method of Problem Solution	[problem-solving] (M3N5) → 3rd (2A)	N/A	3rd	
1.6: Numerical Accuracy	[percent] (M5N5) → 5th (2A)	N/A	5th	
Chapter 2: Statics of Particles				
2.1: Introduction **Forces in a Plane**	[four operations] (M1N3) → 1st (2A) + (M2N3) → 2nd (1A), or (M7N1) → 7th (2A)	[force] (S4P3) → 4th (3A)	4th	9th

Summary of Table 8 (pp. 58-80):
Whole Chapters of Pre-Calculus Statics Topics Appropriate for 9th Grade

- **Chapter 1 (Introduction):** Addition and subtraction of force vectors are to be taught as a special mathematics topic;
- **Chapter 2 (Statics of Particles):** 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).
- **Chapter 3 (Rigid Bodies - Equivalent Systems of Forces):** 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.
- **Chapter 4 (Equilibrium of Rigid Bodies):** Summation or $\sum$ notation should be taught as a special mathematics topic.
- **Chapter 6 (Analysis of Structures):** The Six Trigonometric Functions are to be taught as a special mathematics topic.

Skipping Chapter 5 (Distributed Forces - Centroids and Centers of Gravity) will not affect the smooth transition from Chapter 4 topics to Chapter 6 topics. 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/).

Summary of Table 8 (pp. 58-80):
Whole Chapters of Pre-Calculus Statics Topics Appropriate for 9th Grade

- **Chapter 1 (Introduction);**
- **Chapter 2 (Statics of Particles);**
- **Chapter 3 (Rigid Bodies - Equivalent Systems of Forces);**
- **Chapter 4 (Equilibrium of Rigid Bodies);**
- **Chapter 6 (Analysis of Structures).**

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

Proposed strategy:

- **At 9th Grade:** Statics principles and formulas covered in the 5 chapters could be used to develop the statics portion of a high school statics and dynamics course.
- **Prior to 9th Grade:** Some general knowledge associated with these topics could be incorporated into general science study, as an introduction to engineering foundation.

Summary of Table 8 (pp. 58-80):
Whole Chapters of Calculus-Based Statics Topics

The following chapters involve substantial application of beginning calculus (integration and differentiation), logarithmic and other functions (featured at 11th for Option % and 12th Grade for Options 1-4 in the Math Course Sequence) :

- **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).

Skipping Chapter 5 (Distributed Forces - Centroids and Centers of Gravity) will not affect the smooth transition from Chapter 4 topics to Chapter 6 topics.

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.

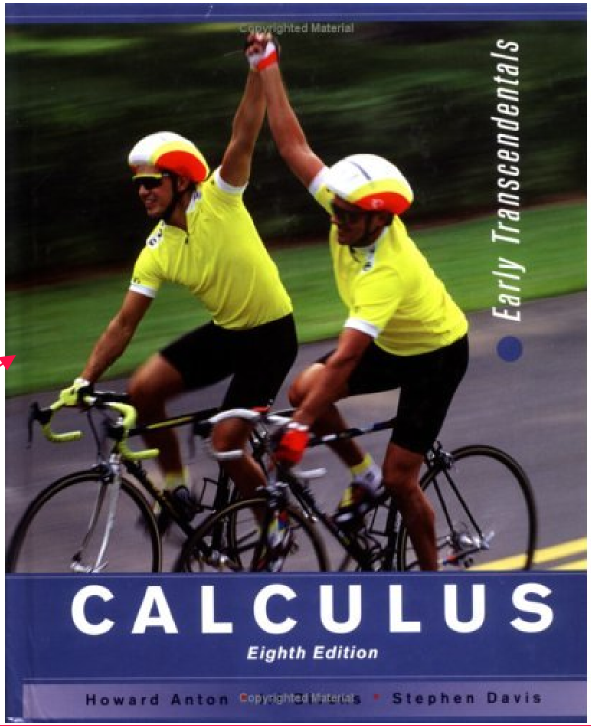
Math & Science Pre-requisite Topics & Completion Grade (Georgia Performance Standard Code) [Pre-requisite Math Skills/Science Principles] (GPS Code) → Grade (Table No.)		Possible Grade to Start the Topic	
Math	Physics	Sec	Ch
[integration] → 12th (to be taught) [differentiation] → 12th (to be taught) [trigonometric functions] (MA2G2) → 10th (2F) → To be taught as a special math topic [scalar product] → To be taught as a special math topic [coordinate system] (M4G3) → 4th (2B) [partial differentiation] → 12th (to be taught)	[force] (S4P3) → 4th (3A) or (S8P3) → 8th (3C) [work] (S8P3) → 8th (3C) [potential energy] (SP3) → 9th (3C)	PS	PS

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.

Calculus Skills in Undergraduate Engineering Foundation Courses

- **Particular skills** in (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**.
- **NOT all skills taught** in all required calculus courses which (1) are usually the same as those required of students majored in mathematics; and (2) are aimed at building a comprehensive calculus skill set.

Chapter 7 (Applications of the Definite Integral in Geometry, Science and Engineering, pp. 442-509): (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.**



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Possibility for "Highly-Talented" Students

The beginning calculus-based statics topics in Chapters 5, 7, 8, 9 and 10 could still be infused into high school engineering curriculum and taught to mathematically "highly talented" students enrolled in Option 5 as extra learning materials, provided that relevant beginning calculus and logarithmic concepts and computational skills are covered at the start of the topics.

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5/07

Georgia Department of Education
Secondary Mathematics
Guidance for Course Sequences under the Georgia Performance Standards

Georgia Performance Standards (GPS) Math Course Sequence					
	Option 1	**Option 2**	**Option 3**	**Option 4**	**Option 5**
Grade			**Advanced**	**Accelerated**	**Accelerated**
6th	6th Grade GPS	6th Grade GPS	6th Grade Advanced GPS	6th, 7th, and 8th grade GPS	6th, 7th, and 8th grade GPS
7th	7th Grade GPS	7th Grade GPS	7th Grade Advanced GPS		
8th	8th Grade GPS	8th Grade GPS	8th Grade Advanced GPS	Math 1	Accelerated Math 1
9th	Math 1	Accelerated Math 1	Accelerated Math 1	Math 2	Accelerated Math 2
10th	Math 2	Accelerated Math 2	Accelerated Math 2	Math 3	Accelerated Math 3
11th	Math 3	Accelerated Math 3	Accelerated Math 3	Math 4	AP Statistics*; AP Calculus AB/BC; Joint Enrollment
12th	Math 4; AP Statistics*; Discrete Math	AP Calculus AB/BC; AP Statistics*; Discrete Math; Joint Enrollment	AP Calculus AB/BC; AP Statistics*; Discrete Math; Joint Enrollment	AP Calculus AB; AP Statistics*; Discrete Math; Joint Enrollment	AP Statistics*; AP Calculus AB/BC; Joint Enrollment

*AP Statistics may be taken concurrently with an upper level math course at the system's discretion.

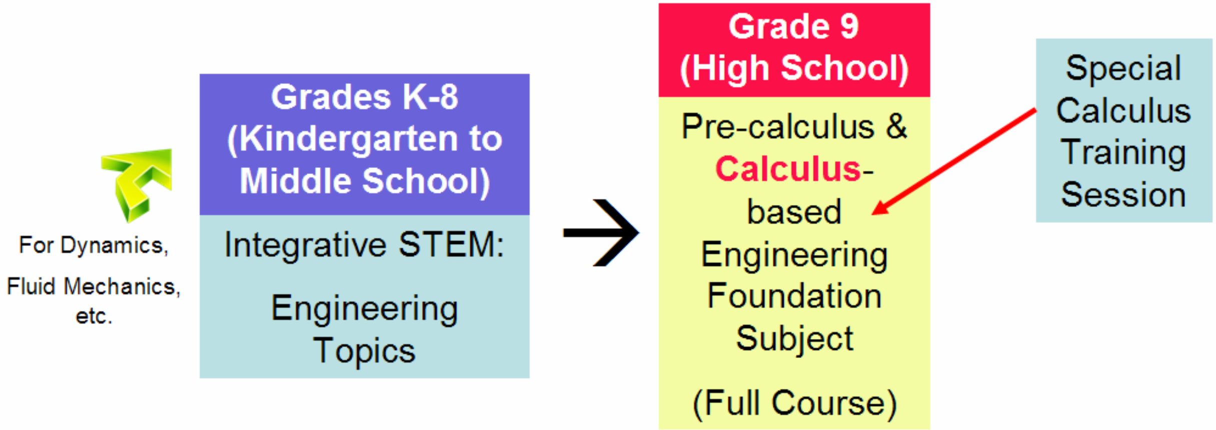
Proposed Strategy for "Average" High School 9th Grade Students to Learn Calculus-Based Statics Topics

- **Development of some short-term calculus training sessions:** To allow average 9th Grade students to master particular set of calculus computational skills relevant to engineering topics (instead of waiting for them to complete two full calculus courses before proceeding to the study of beginning-calculus based engineering topics).

- **Application:** For 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:** 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; 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.

The Special Calculus Training Session Approach for Calculus-based Topics



- **In math courses:** Strict adherence to pre-requisite sequence is very important.

- **In engineering course:** 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.

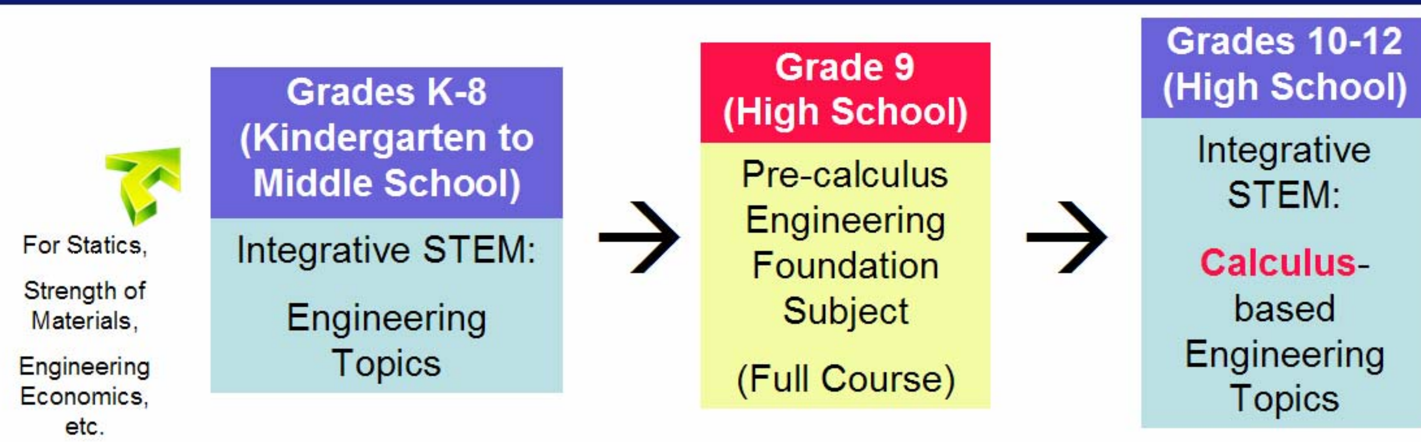
Proposed Strategy for "Average" High School 9th Grade Students to Learn Calculus-Based Statics Topics

- **Two-stage strategy:** (1) Students at 9th, 10th and 11th Grades could concentrate on studying high school appropriate pre-calculus portion of engineering foundation topics. (2) 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:** For those engineering subjects with smaller portion of calculus-based topics, such as statics and strength of materials.

- **Potential advantages:** (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.

The Integrative STEM Approach for Calculus-based Topics



The Special Calculus Training Session Approach for Calculus-based Topics

For Dynamics,

Fluid Mechanics, etc.

Grades K-8 (Kindergarten to Middle School)

Integrative STEM:

Engineering Topics

→

Grade 9 (High School)

Pre-calculus & **Calculus**-based Engineering Foundation Subject

(Full Course)

Special Calculus Training Session

The Integrative STEM Approach for Calculus-based Topics

For Statics,

Strength of Materials,

Engineering Economics, etc.

Grades K-8 (Kindergarten to Middle School)

Integrative STEM:

Engineering Topics

→

Grade 9 (High School)

Pre-calculus Engineering Foundation Subject

(Full Course)

→

Grades 10-12 (High School)

Integrative STEM:

Calculus-based Engineering Topics

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

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: (1) Table 9 for pre-calculus portion; and (2) Table 10 for calculus portion.

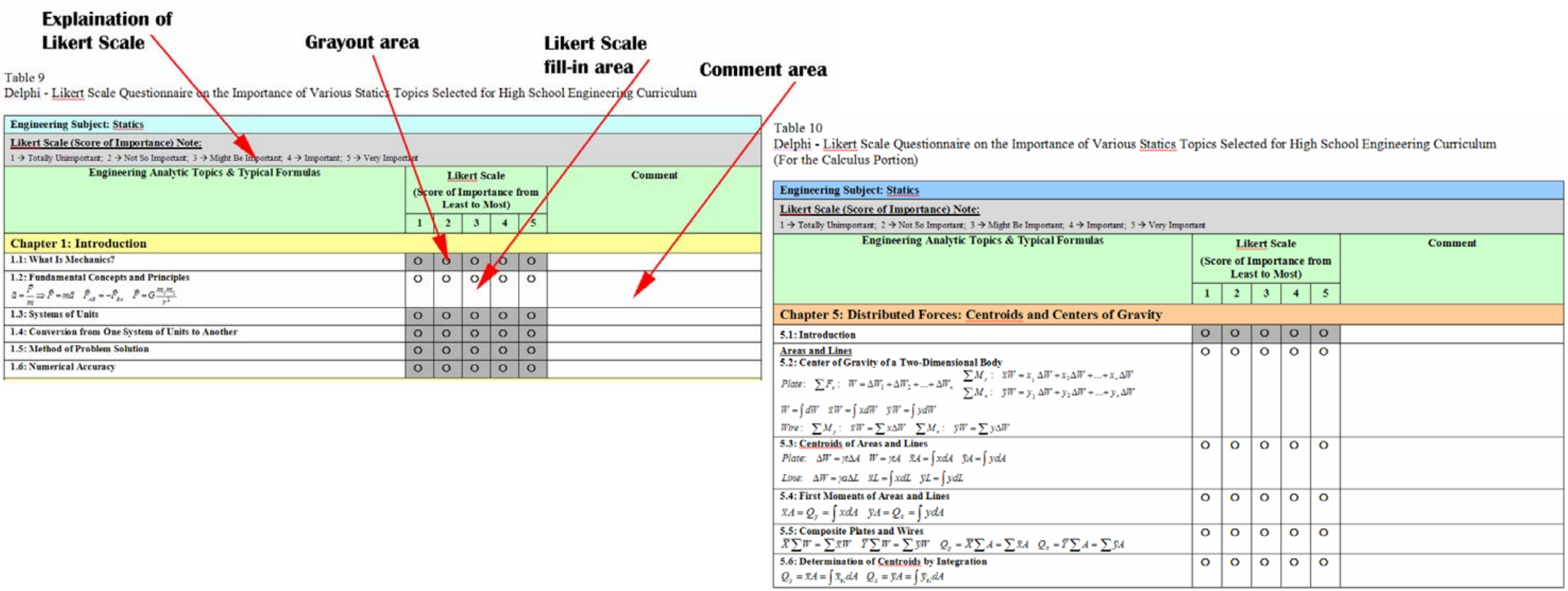


Table 9
Delphi - Likert Scale Questionnaire on the Importance of Various Statics Topics Selected for High School Engineering Curriculum

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?	O	O	O	O	O	
1.2: Fundamental Concepts and Principles $\vec{a}=\frac{\vec{F}}{m}\Rightarrow\vec{F}=m\vec{a}$ $\vec{F}_{AB}=-\vec{F}_{BA}$ $F=G\frac{m_1m_2}{r^2}$	O	O	O	O	O	
1.3: Systems of Units	O	O	O	O	O	
1.4: Conversion from One System of Units to Another	O	O	O	O	O	
1.5: Method of Problem Solution	O	O	O	O	O	
1.6: Numerical Accuracy	O	O	O	O	O	

Table 10
Delphi - Likert Scale Questionnaire on the Importance of Various Statics Topics Selected for High School Engineering Curriculum
(For the Calculus Portion)

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 5: Distributed Forces: Centroids and Centers of Gravity						
5.1: Introduction	O	O	O	O	O	
Areas and Lines 5.2: Center of Gravity of a Two-Dimensional Body Plate: $\sum F_z: W=\Delta W_1+\Delta W_2+...+\Delta W_n$ $\sum M_y: \bar{x}W=x_1\Delta W+x_2\Delta W+...+x_n\Delta W$ $\sum M_x: \bar{y}W=y_1\Delta W+y_2\Delta W+...+y_n\Delta W$ $W=\int dW$ $\bar{x}W=\int x dW$ $\bar{y}W=\int y dW$ Wire: $\sum M_y: \bar{x}W=\sum x\Delta W$ $\sum M_x: \bar{y}W=\sum y\Delta W$	O	O	O	O	O	
5.3: Centroids of Areas and Lines Plate: $\Delta W=\gamma t\Delta A$ $W=\gamma tA$ $\bar{x}A=\int x dA$ $\bar{y}A=\int y dA$ Line: $\Delta W=\gamma a\Delta L$ $\bar{x}L=\int x dL$ $\bar{y}L=\int y dL$	O	O	O	O	O	
5.4: First Moments of Areas and Lines $\bar{x}A=Q_y=\int x dA$ $\bar{y}A=Q_x=\int y dA$	O	O	O	O	O	
5.5: Composite Plates and Wires $\bar{X}\sum W=\sum \bar{x}W$ $\bar{Y}\sum W=\sum \bar{y}W$ $Q_y=\bar{X}\sum A=\sum \bar{x}A$ $Q_x=\bar{Y}\sum A=\sum \bar{y}A$	O	O	O	O	O	
5.6: Determination of Centroids by Integration $Q_y=\bar{x}A=\int \bar{x}_{el}dA$ $Q_x=\bar{y}A=\int \bar{y}_{el}dA$	O	O	O	O	O	

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

Why Establishing the Order of Importance for Various Statics Topics through a Five-Point Likert Scale Survey?

- **“Politics” of existing K-12 curriculum structure:** 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.

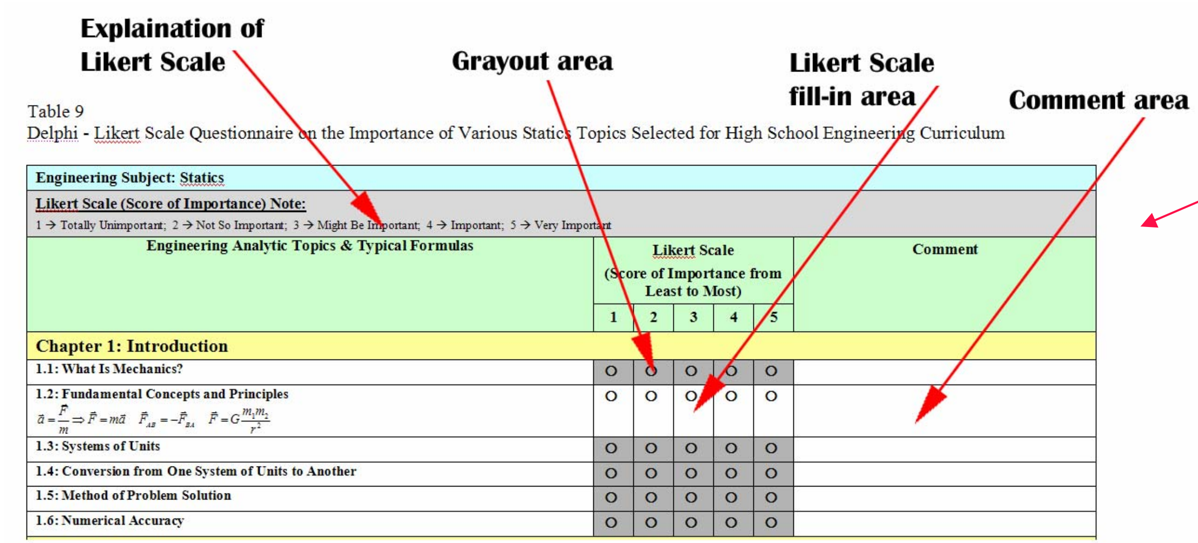
- **Treatment:** We should collect expert opinions of the relative importance of various topics, through a 5-point Likert survey study.

- **Goals of the survey:** 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.

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

The Survey Form & Analysis of Results

- **Gray-out area:** Some statics topics covered in sections of the selected textbook (Beer et al, 2004) are absolutely needed 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; and should be included anyway regardless of their perceived importance based on expert opinion.
- **Analysis of survey results:** Statistic analysis will be made on collected survey forms to compute the means of scores of importance for each topic. 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**.



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1.4: Conversion from One System of Units to Another	O	O	O	O	O	
1.5: Method of Problem Solution	O	O	O	O	O	
1.6: Numerical Accuracy	O	O	O	O	O	

- **Basic question for the survey:**
- 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.

Review & Validation of Survey Instruments by Expert Faculty at UGA & NCETE (Tables 8, 9, & 10)

To be submitted for review, validation, and approval:

- 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);
- Table 10 (Delphi - Likert Scale Questionnaire on the Importance of Various Statics Topics Selected for High School Engineering Curriculum For The Calculus Portion).

Authorities to give review, validation, and approval:

- University of Georgia engineering professors, Dr. Robert Wicklein, Dr. John Mativo and Dr. Sidney Thompson. (1) 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, in terms of their respective fulfillment of mathematics and physics pre-requisites at various grade levels, as mandated by Georgia Performance Standards; (2) 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.
- NCETE leader Dr. Kurt Becker at Utah State University as well as other appropriate authorities for a final approval.

Potential Survey Participants

- **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;

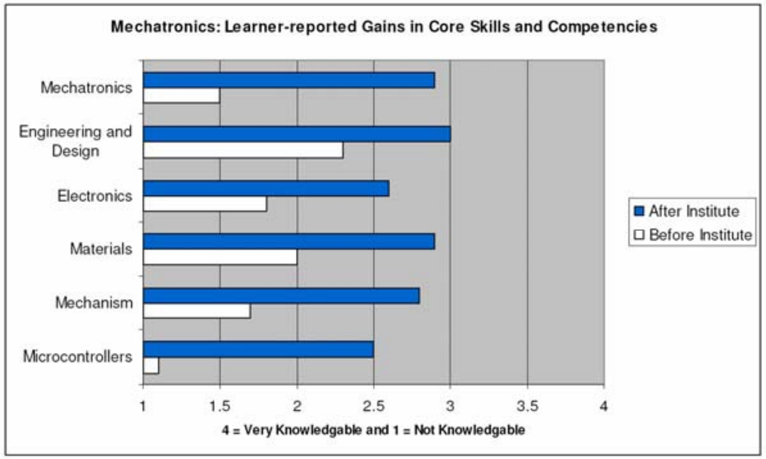
- **Group 5 (Practicing Engineers and Technicians):** To be selected among members of relevant professional associations, such as American Society of Mechanical Engineers, American Society of Civil Engineers and others.

Developing Appropriate Pedagogic Strategy for K-12 Engineering Curriculum

Differences between High School and College Students and Pedagogic Strategy for K-12 Engineering Curriculum: Compared to college students, high school students usually have lower degree of cognitive maturity and less ability to understand complicated and abstract scientific concepts.

Possible strategy for developing the analytic and predictive abilities of high school students enrolled in engineering pathways:

- 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.);
- **Integrating three learning methods**: (1) analytic ("pencil & paper;" (2) experimental (lab); and (3) simulation (software).
- Providing **well-organized instructional materials** appropriate to their age.
- **Project-Based Learning (PBL).** 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.



Important Considerations to be Taken

Inspiration: "A unified curriculum framework for technology education" (Rojewski & Wicklein, 1999).

Means and ends

To foster K-12 students' real ability in innovative engineering design 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. ✓

To make K-12 students instruments of computations using engineering related formulas. 🚫

Although this is a necessary task ✓

Focus on problem-solving

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. ✓

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. 🚫

Important Considerations to be Taken

Understanding the nature of engineering

Engineering is essentially applied science → Train high school students into potentially creative designers of innovative products and systems.

To turn high school students into well-programmed testing robots

<u>Project-Based Learning:</u> a good model for systematically deliver well-organized and cohesively-related sets of engineering analytic principles and skills to high school students.

Real Age Appropriate Design Ability

Although testing is needed.

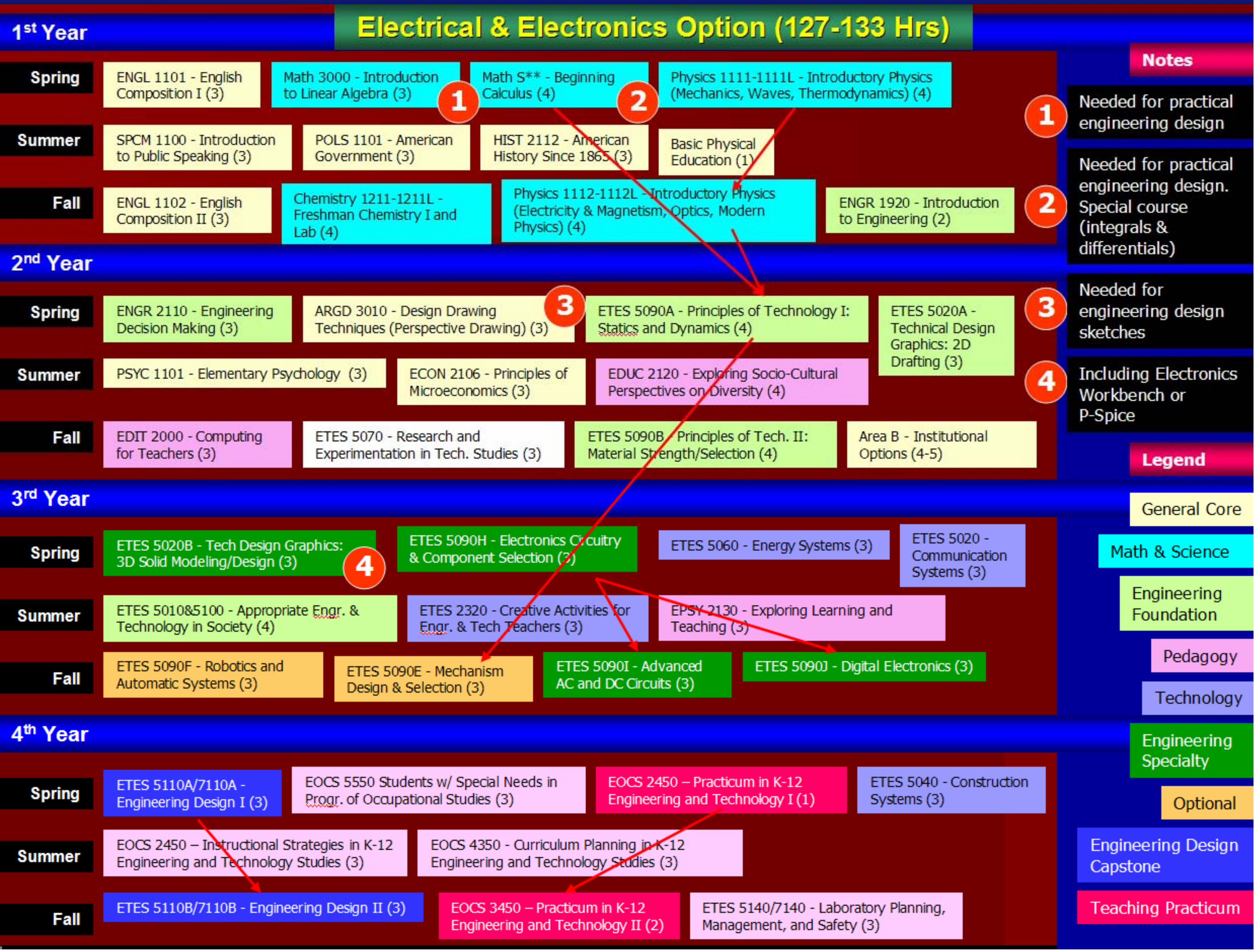
- Understand the essentials of engineering design process
- Possess solid mastery of the basic analytic and predictive principles and skills
- Know how to independently explore new topics, to learn on their own, and to locate knowledge and information

Vision for Engineering-Oriented Professional Development

The Vision statement: "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: This vision 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.

Vision for Engineering-Oriented Professional Development



Content of the vision:

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.

The Advantages of the Vision

- **Amphibious talents for both schools and industry**: 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). 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.
- **System approach and long-term strategy:** Offers 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 sporadic short-term training sessions focused on technology alone under the currently dominant model of professional development. 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.
- **A practical balance between "process-oriented engineering skills" and "core engineering concepts":** Well-organized courses allows future high school engineering and technology teachers to possess sufficient subject-specific knowledge ("core engineering concepts"); a series of "capstone" courses and engineering-specific pedagogic courses provide "process-oriented engineering skills." Both form a dialectic and symbiotic relationship.

"System Thinking"

Professional Development for Future K-12 Engineering and Technology Teachers

Different stages of K-12 curriculum needs different types of professional development:

- **Kindergarten and elementary school (Grades K-5):** (1) Exposure 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.); (2) basic mathematics skills (four operations, measurements, and others); and (3) creative and conceptual design of "science fiction" types. → **Teachers' professional development:** 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. → Creative Activities for Engineering and Technology Teachers (3 credit hours, for the 3rd year) under the proposed B.S. in K-12 Engineering and Technology Teacher Education program. → **This part of the professional development and instructional content delivery could be implemented immediately, without substantial modification of the current programs.**

Professional Development for Future K-12 Engineering and Technology Teachers (Cont.)

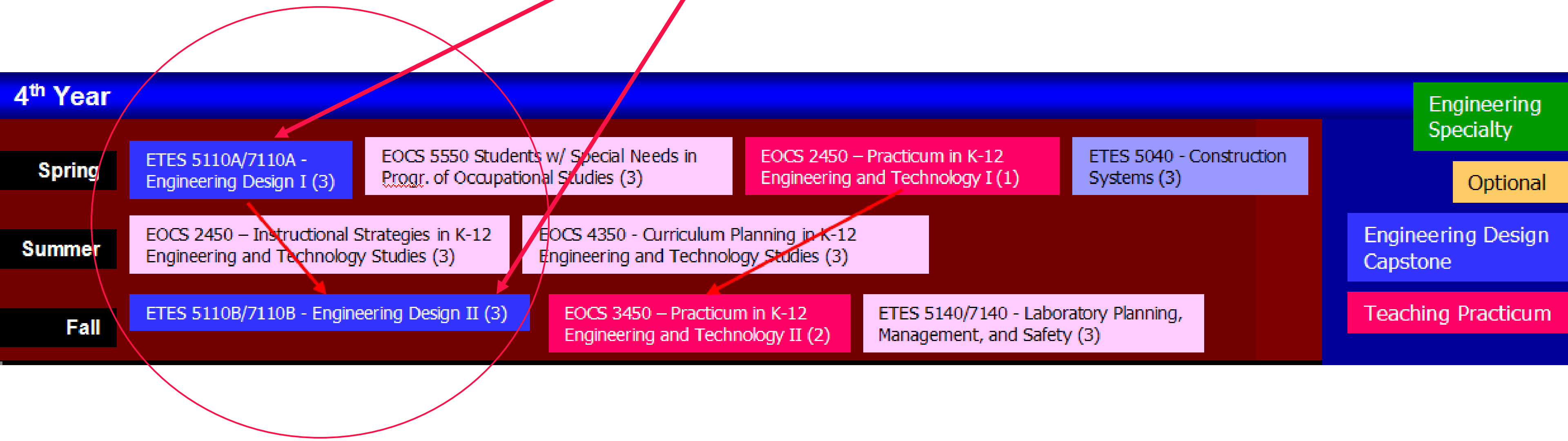
- **Middle School (Grades 6-8):** (1) Engineering and technology experiments; (2) "trial-and-error" based technology design process; (3) traditional and modern technology as applications of engineering (CAD, CAM, wood, plastic and metal working processes. → **Teachers' professional development:** Current 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. → Technology courses in the B.S. in K-12 Engineering and Technology Teacher Education program developed under my previously presented Proposed Model. → **This part of the professional development and instructional content delivery could be implemented immediately, without substantial modification of the current programs.**

Professional Development for Future K-12 Engineering and Technology Teachers (Cont.)

- **High school (Grades 9-11):** (1) Hard-core pre-calculus level engineering analytic principles and skills; (2) simple engineering design projects using these analytic principles and skills with the "Analytic Reduction" model of engineering design process and engineering-related technology skills (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; no short-term training session would adequately address this problem. → **The implementation of the B.S. in K-12 Engineering and Technology Teacher Education program developed under my previously proposed model (Appendix A1) would adequately address this issue.**

Professional Development for Future K-12 Engineering and Technology Teachers (Cont.)

- **High School Graduation Year (Grade 12):** Moderately complex engineering design project using “System Thinking” model of engineering design. → **Teachers’ professional development:** The two “Capstone” **Engineering Design** courses of the B.S. in K-12 Engineering and Technology Teacher Education program developed under my previously proposed model would adequately address this issue.



Curricular Development

- **Relying on the strength of current K-12 technology curriculum developers:** Many engineering analytic principles and 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:** According to the organization's presentation during ITEA 2009 Conference held on March 26-28 in Louisville, Kentucky, Engineering by Design (developed by ITEA, http://www.iteaconnect.org/EbD/ebd.htm) charges each participating State in the U.S. 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).

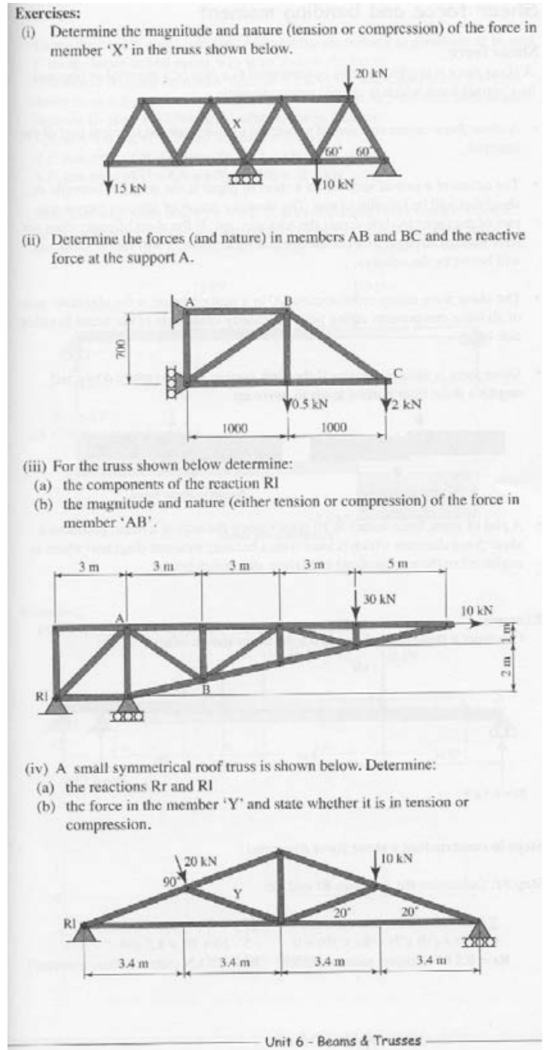
- **Providing guidelines is the only role for public institution to play:** The major shortcoming of these programs is that they are more-or-less based on "trial-and-error" technology design process, rather than on solid engineering analytic principles and formula-based predictive computations. Nevertheless, 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.**

Grass-Root Initiative is the American Way!

Relying on the Strength of the People in the Field!

Curricular Development (Cont.)

- **International exchange and cooperation:** For some subjects such as statics, other English-speaking nations such as Australia have achieved great success, with well developed curriculum structure, instructional materials, and evaluation instruments. In such case, there should be no need to re-invent the wheel but to improve upon existing invention; and using other countries' achievement as a starting point should be considered as a cost-effective option.



Exercises:

(i) Determine the magnitude and nature (tension or compression) of the force in member 'X' in the truss shown below.

(ii) Determine the forces (and nature) in members AB and BC and the reactive force at the support A.

(iii) For the truss shown below determine:

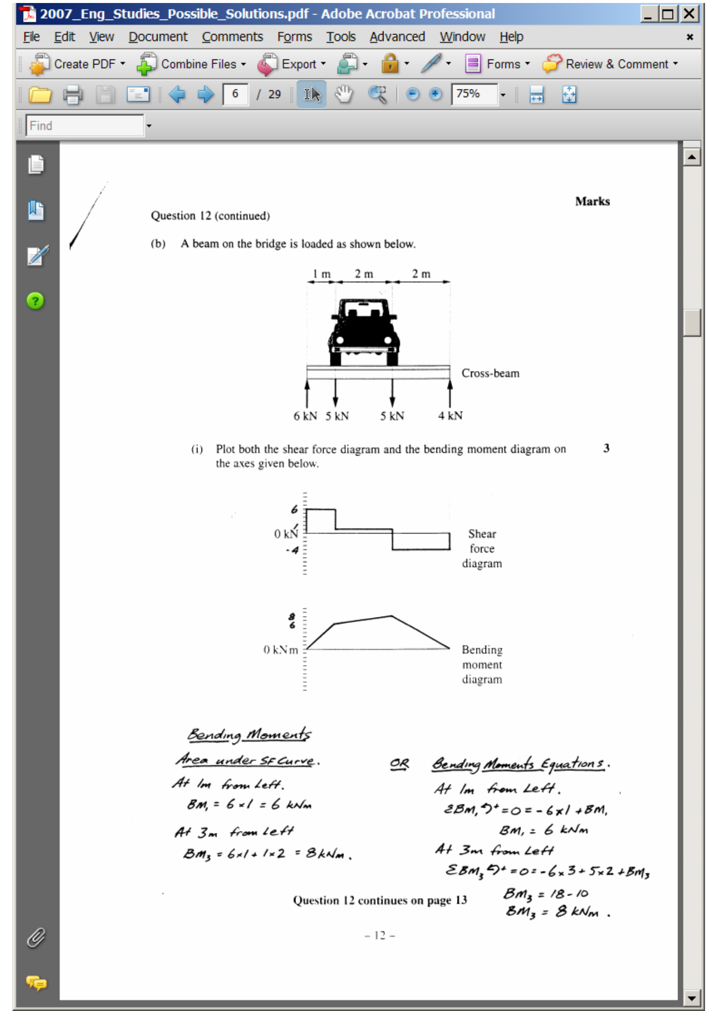
(a) the components of the reaction Rl

(b) the magnitude and nature (either tension or compression) of the force in member 'AB'.

(iv) A small symmetrical roof truss is shown below. Determine:

(a) the reactions Rr and Rl

(b) the force in the member 'Y' and state whether it is in tension or compression.



Question 12 (continued)

Marks

(b) A beam on the bridge is loaded as shown below.

(i) Plot both the shear force diagram and the bending moment diagram on the axes given below. 3

Bending Moments

Area under SF Curve.

At 1m from Left.

$BM_1 = 6 \times 1 = 6$ kNm

At 3m from Left

$BM_3 = 6 \times 1 + 1 \times 2 = 8$ kNm.

OR

Bending Moments Equations.

At 1m from Left.

$\Sigma BM_1 = 0 = -6 \times 1 + BM_1$

$BM_1 = 6$ kNm

At 3m from Left

$\Sigma BM_3 = 0 = -6 \times 3 + 5 \times 2 + BM_3$

$BM_3 = 18 - 10$

$BM_3 = 8$ kNm.

Question 12 continues on page 13

High school statics teaching and testing materials used in Australia.

Let Foreign Things Serve American needs!

Administrative & Financial Impacts

- **"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.

$$$+–

Be Not Only Penny-Wise and Also Pound-Intelligent!

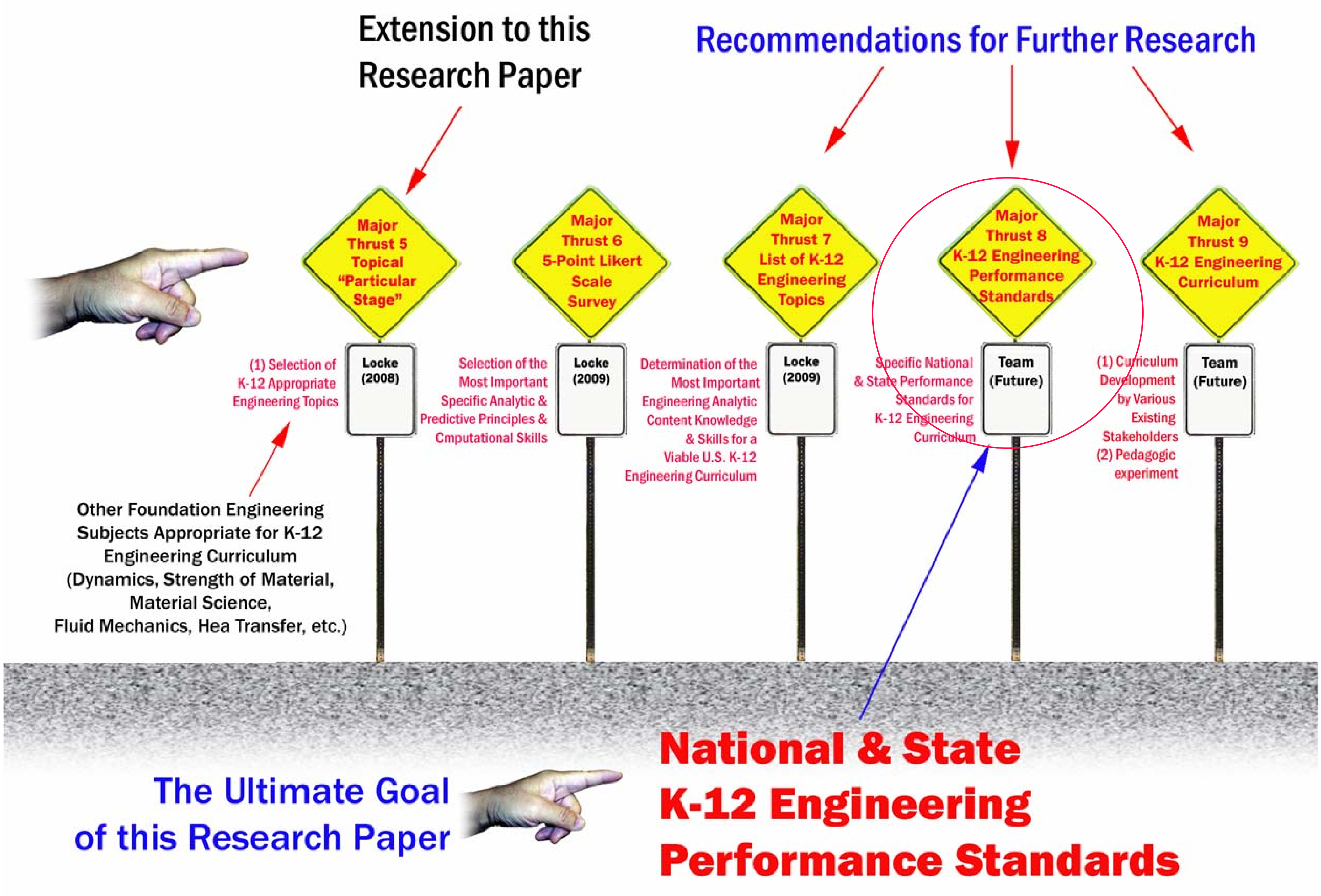
Relying on the Strength of the People in the Field!

Recommendations for Further Research

1. 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;
2. 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;
3. A "**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;
4. 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;
5. 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 3rd item, and the national or state performance standards to be developed in the 4th item.
6. Well-designed **pedagogic experiments** could be conducted for the development of functional models of K-12 engineering pedagogy.

University of Georgia Engineering Program	University of Georgia Engineering Foundation Courses								
	ENGR 1120 Graphics & Design	ENGR 2120 Statics	ENGR 2130 Dynamics	ENGR 2140 Strength of Materials	ENGR 3160 Fluid Mechanics	ENGR 3140 Thermo-dynamics	ENGR 3150 Heat Transfer	ENGR 2920 Electrical Circuits	ENGR 2110 Engr. Decision Making

The Ultimate Goal



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