NCETE Core 4 Research Paper

Selected Topics: Others Approved

(Under the General Topics of "Engineering Design in Secondary Education" and of "Vision and Recommendations for Engineering-Oriented Professional Development")

HIGH SCHOOL APPROPRIATE ENGINEERING CONTENT KNOWLEDGE IN THE INFUSION OF ENGINEERING DESIGN INTO K-12 CURRICULUM: STATICS

NCETE Core 4 - Engineering Design in STEM Education

Spring 2009

College of Education

University of Georgia

Professors: Dr. Kurt Becker (Utah State University) and

Dr. Mark Tufenkjian (California State University Los Angeles)

Advisors: Dr. Robert Wicklein, Dr. John Mativo, and Dr. Sidney Thompson

Student: Edward Locke (elocke@uga.edu)

PART ONE

Introduction

"Technology education is a field of study that seeks to promote technological literacy for all students." In the United States, technology education has been part of the K-12 curriculum and is undergoing changes in recent decades in the direction of infusing engineering design as an important factor in the curriculum (Smith, 2006, pp. 1-3). The infusion of engineering design includes two major components: (1) specific engineering analytic principles and skills; and (2) generic engineering design process. The first component, specific engineering analytic principles and skills, is the foundation for infusing engineering design into K-12 curriculum, but for various reasons, has not been thoroughly explored yet; thus, it will be the focus of this Research Paper. The second component has been sufficiently studied by many scholars, and thus, is beyond the concern of this Research Paper.

Purpose of this Research Paper

The Particular or Immediate Purpose of the Research Paper

This Research Paper seeks to identify high school appropriate engineering content knowledge (to be more specific, the analytic and predictive principles plus computational formulas) related to the subject of statics, using rationally established criteria and procedures. These topics, principles and associated formulas will be selected from 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).

The General or Ultimate Aim of this Research Paper and its Seamless Connection to NCETE Research Agenda

The criteria and procedures used in this Research Paper will be used as a working model for identifying high school appropriate engineering content knowledge in other subjects (such as dynamics, fluid mechanics, mechanism design, thermodynamics, heat transfer, and engineering economics or decision-making), which shall constitute the major endeavors of my dissertation research aimed at

1. <u>Infusion of engineering design into secondary education</u>: Creating 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 (such as statics and dynamics, material strength and selection, fluid and aerodynamics, mechanism design and selection, etc.). This could serve as a reference for systematically infusing engineering design into K-12 curriculum, through collaborative efforts of many stakeholders in K-12 engineering and technology education;
2. <u>Vision and recommendations for engineering-oriented professional development</u>: Developing a working model for systematically training new generations of K-12 engineering and technology teachers who could implement K-12 engineering and technology curriculum.

The above two aims could be integrated into the general topics of "Professional Development Models to Infuse Engineering Design in Secondary Education" and of

"Vision and Recommendations for Engineering-Oriented Professional Development," as listed in the Core 4 Research Paper Activity information sheet.

Potential Significance of this Research Paper

This Research Paper seeks to make a meaningful contribution to the national endeavors for improving K-12 engineering and technology teacher preparation, in the direction of infusing greater amount of specific engineering analytic and predictive knowledge content. This objective is in the same direction of the new B.S. Degree in Engineering & Technology Education (T&E in STEM) at Utah State University, to be implemented in the coming Fall Semester, 2009. This new direction is also reflected in the *Proposed Model for Infusing Engineering Design into K-12 Curriculum*, which I have presented in the International Technology Education Association 71st Annual Conference held in the Kentucky International Convention Center (Friday March 27, 2009, in Louisville, Kentucky), under the sponsorship of Dr. John Mativo, from the University of Georgia (Appendix 1). After the conference, this *Proposed Model* has been presented to faculty at the University of Georgia and further improved with workable Academic Flow Charts for a B.S. Degree in K-12 Engineering and Technology Teacher Education (*Figures 1A and 1B*). This Research Paper is essentially focused on high school appropriate engineering analytic content knowledge for the subject of statics.

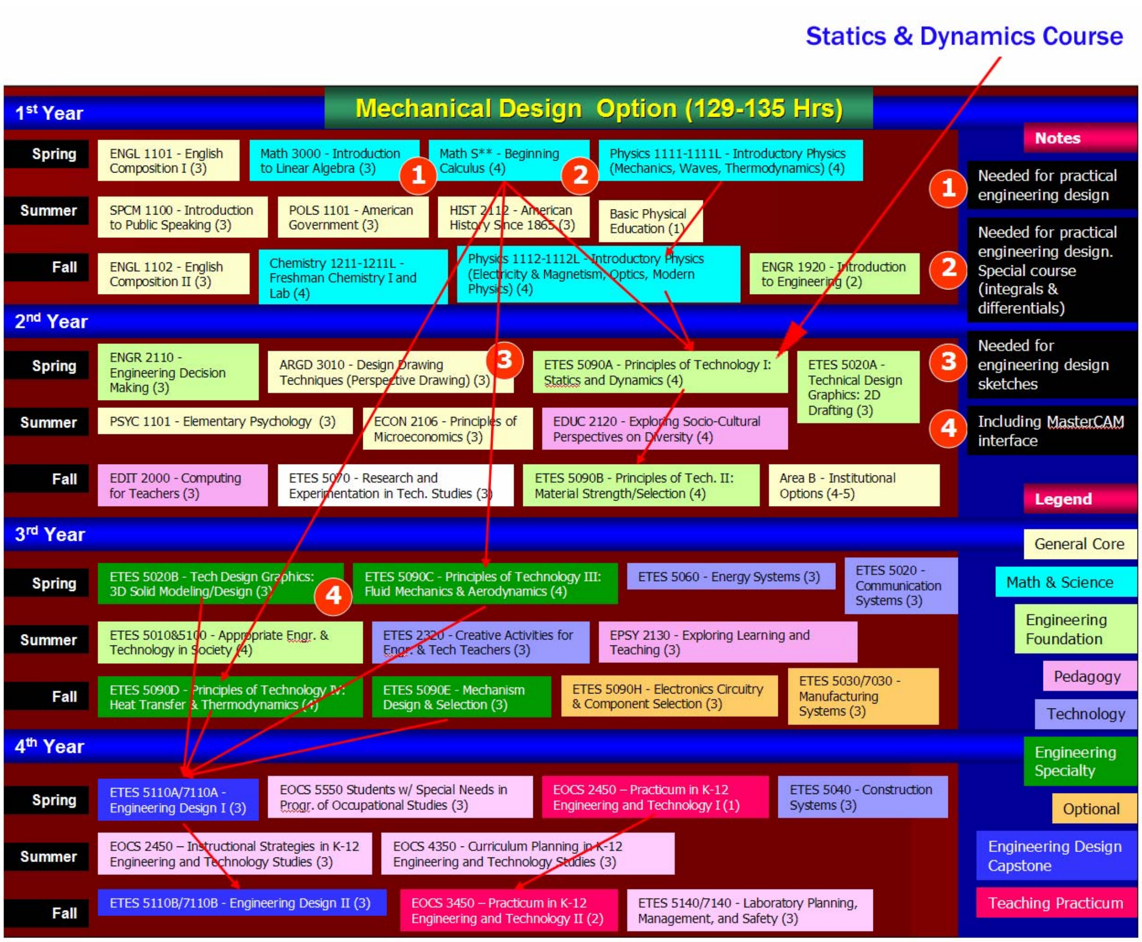

Figure 1A. The Statics course in the Academic Flow Chart for the Mechanical Design Option of the proposed K-12 Engineering and Technology Teacher Education program.

Research Question

This Research Paper seeks to answer this 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 (from kindergarten and elementary school, through middle school, to high school and the graduation year), in terms of matching these students’ level of mastery of foundation mathematics skills, science principles and problem-solving skills?”

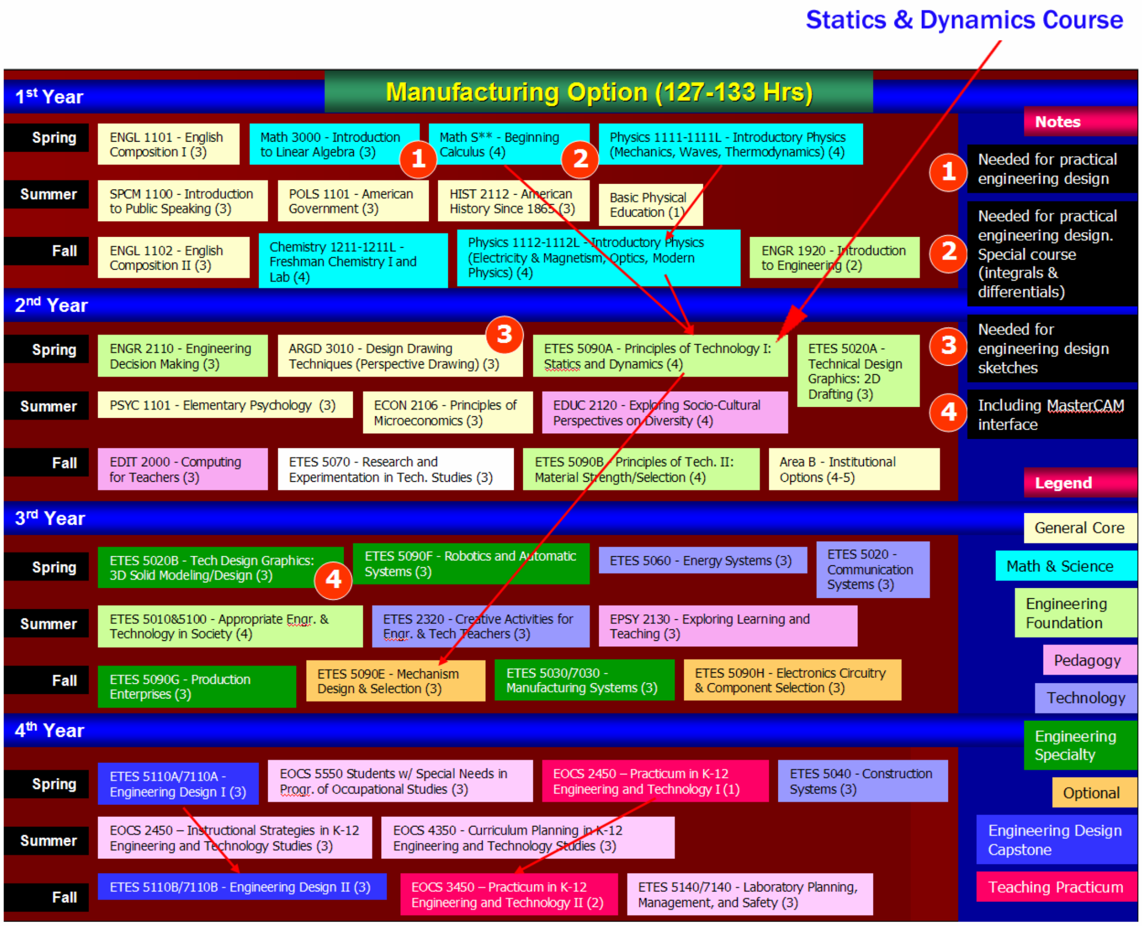

Figure 1B. The Statics course in the Academic Flow Chart for the Manufacturing Option of the proposed K-12 Engineering and Technology Teacher Education program.

PART TWO

REVIEW OF LITERATURE

Rationales for this Research Paper

One of the most important rationales for this Research Paper is 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, through the improvement of current K-12 engineering and technology curriculum, as well as related teacher education program, which shall be aimed at training highly qualified teachers for

- <u>All future K-12 students</u>: 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);
- <u>Engineering-oriented K-12 students</u>: Unlike mathematics, chemistry and physics, K-12 engineering curriculum remains skeletal so far; its main focus is on generic design process; and its analytic and predictive knowledge contents are restricted to a few areas (such as CAD, electronics, and robotics), and are generally not cohesively and systematically organized. Due to the fact that engineering is a "tough" major to pursue and that its heavy-duty STEM content often is or appears to be 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 that is similar to what K-12 mathematics, chemistry and physics currently have. This would help future high school students to succeed in their engineering and technology career pathways.

Previous Scholarly Endeavors at Infusion of Engineering Design into K-12 Technology Education

Existing Models to Help Solving the Problem of Shortage in Engineering Graduates

Shortage in engineering graduates in the United States has been reported by many scholars and business leaders. For example, Wicklein (2006, p. 29) indicated that in the United States, "currently, engineering education has close to a 50% attrition rate for students. [The State of] Georgia currently seeks 50% of the engineering workforce from out-of-state sources." This Research Paper is particularly aimed at promoting a long-term and comprehensive strategy for solving this problem.

To help solve the problem of a shortage in engineering graduates, tremendous amount of efforts have been made across the United States to prepare high school students for a college engineering education by injecting engineering design content into K-12 curriculum. Many models of high-school engineering curriculums such as *Project Lead The Way* (PLTW, http://www.pltw.org/) and *High School That Works* (HSTW, http://www.sreb.org/programs/hstw/hstwindex.asp) have been tested across the Nation. Most of these models, however, are focused on getting high school students involved in contextual, hands-on design projects, using a technology education design process (*trial* *and error*), rather than on learning and applying scientific principles and mathematics-based analytical and predictive skills required to solve engineering design problems.

New Ideas for a Cohesive and Systemic Improvement of K-12 Engineering and Technology Education in the United States

Scholarly advice: Some scholars are calling for making engineering design the focus of high school technology education, and for incorporating these principles and skills into high school curriculum. Wicklein proposed using engineering design as the integrating factor linking engineering and science through high school technology programs (2006, p. 25), explaining that “Engineering design provides an ideal platform for integrating mathematics, science, and technology” (Wicklein, 2008). As mentioned before, the infusion of engineering design includes two major components: (1) specific engineering analytic principles and skills; and (2) generic engineering design process.

Lewis (2007, pp. 846-848) discussed the need to: (a). establish a “codified body of knowledge that can be ordered and articulated across the grades” with focused attempt to systematize the state of the art in engineering in a way that is translatable in schools (instead of short term efforts focused on a particular topic or unit), and (b). make engineering education a coherent system with the creation of content standards for the subject area, in line with science and technology education. This Research Paper will contribute to the codification of high school appropriate engineering analytic content knowledge related to the subject of statics.

Nature of engineering education: By definition, engineering design is the process of applying scientific knowledge and creativity to solve real-world technical problems; and thus, it could be considered as applied science. At high school level, engineering design could serve as a platform to apply scientific knowledge and skills from mathematics, physics, chemistry, and other courses to authentic life settings, and thus, increase students' interests in learning. Traditionally, science curriculum are organized and managed under a system of codification that makes it possible to sequentially and methodically deliver declarative knowledge content, and up to this point, this system of codification still works; therefore, the principle of codification could probably apply to high school engineering and technology education.

Connection to NCETE Agenda

The idea of injecting engineering design-related analytical skills into high school engineering and technology curriculum is within the frameworks of National Center for Engineering and Technology Education (NCETE) 2008-2009 Research Plans (NCETE, 2008). 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). Traditionally, these principles and skills are taught in lower-division courses of undergraduate engineering programs. However, because 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, so as to streamline their pathway to engineering careers.

<u>My practical vision</u>: In my opinion, to solve the problem of chronic shortage of engineering graduates in the United States, we need to offer K-12 students better preparation for college-level engineering majors; and selectively teaching high school appropriate engineering knowledge content, which up to this point, remains the domain

of university undergraduate engineering programs, shall be an important part of such preparation. I have discussed this idea with engineering professors at the University of Georgia, including Dr. John Mativo, Dr. David Gattie, and Dr. Sidney Thompson, and have received positive feedback. In addition, during the 71st Annual Conference of International Technology Education Association, I am informed that 10% of all public high schools in Australia have implemented engineering program (for details, refer to Appendices 2A and 2B). In the United States, we have better material conditions for improving K-12 education; thus, we could perform better than do schools in Australia.

Importance of Engineering Analytic Knowledge Content

Core engineering concepts "go beyond tool skills….and beyond the digital skills that have captured the interest of the profession over the past two decades. Tools will change but even more important is the cognitive content and intellectual processes fundamental to effective technological problem solving and literacy" (Sanders, 2008, p. 6). Borko (2004) intensively evaluated a professional development program at a school site and concluded that in order to foster students' conceptual understanding, teachers must have a rich and flexible knowledge of the subject they teach, including the central facts and concepts of the discipline.

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

Necessary Components for Engineering-Oriented Professional Development

Learning from established pedagogic practice in mathematics and science education: Engineering curriculum at K-12 level is a part of the generic STEM program; and in my opinion, should draw extensive reference from the traditional mathematics and science pedagogy. In mathematics and science professional development, teachers must complete a full set of relevant courses, not just a few sporadic and disconnected training sessions. Mastery of the "core engineering concepts" 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; mastery of "process-oriented engineering skills," on the other hand, requires years of practice in classroom teaching, generally can not be achieved within a short period of training that lasts 2 weeks or even 2 or more semester-long courses in undergraduate teacher preparatory programs.

Engineering content knowledge: Mastery of enough content knowledge or core principles is very important in the successful implementation of educational programs. Without content knowledge, pedagogic process is meaningless. Content knowledge is like the wine while pedagogic process (a lesson plan, assessment method and checklist, homework handout and assessment rubric, etc.) is like the bottle that is used to store wine and prevent it from getting lost. Both form an interactive and symbiotic relationship. Burghardt and Hacker (2004, p. 4) concluded that "an important consideration in the design of the lesson plan is that science, engineering, and technology teachers are responsible for teaching and their students are responsible for learning mathematics concepts. This is a non-trivial consideration and one that requires support of the science, engineering, and technology teachers in terms of math content and pedagogy."

Mathematics skills: Mathematic is used in the construction of computational formulas for every branch of science and engineering; thus, relevant courses in mathematics are often classified as pre-requisite for engineering courses (for example, at college level, calculus I is the pre-requisite for statics). In my experience, it is a good practice for engineering teachers to review relevant mathematics at the beginning of any engineering course to make sure that students know how to use predictive analysis formulas correctly.

Differences between Conceptual and Procedural Knowledge

It is meaningless to learn generic "process-oriented engineering skills" (or "procedural knowledge") without first mastering sufficient number of specific "core engineering concepts" ("conceptual knowledge"). Nevertheless, learning of "process-oriented engineering skills" does help future high school engineering and technology educators to master "core engineering concepts," in terms of increasing efficiency in learning, locating pertinent information from library and Internet, and developing curricular units, etc. Without a general understanding of the interconnections among various pieces of knowledge (or "seeing trees without seeing the entire forest"), it is difficult to reach a deep understanding of STEM content. Burghardt and Hacker stated that "as part of the MSTP project, we had gathered student performance data and found that percent, measurement, area, and perimeter were concepts students did not demonstrate understanding of on standardized examinations. In part, the difficulty arose from instruction occurring at too low a level. For instance, in asking math teachers how they taught percents, most gave formulaic answers that failed to develop depth of understanding. When discussing area, the approach was the memorization of an equation with a mnemonic" (2004., p. 2). This example illustrates the need for teachers to be able to connect abstract scientific concepts with simple life experience so as to help students learn. For example, in this case, the teacher could simply let a candy represent one unit, arrange 5 columns of candies, each column containing 3 candies, let student count the total number of candies and explain how multiplication and the concept of area work.

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

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

This Research Paper could be considered as a portion of the 5th Major Thrust in the works of the scholars at the University of Georgia for the improvement of K-12 engineering and technology education in the United States, which generally follow a recursive path from "General Stage" to "Particular Stage" and vice versa, as explained and illustrated in *Figure 2* below.

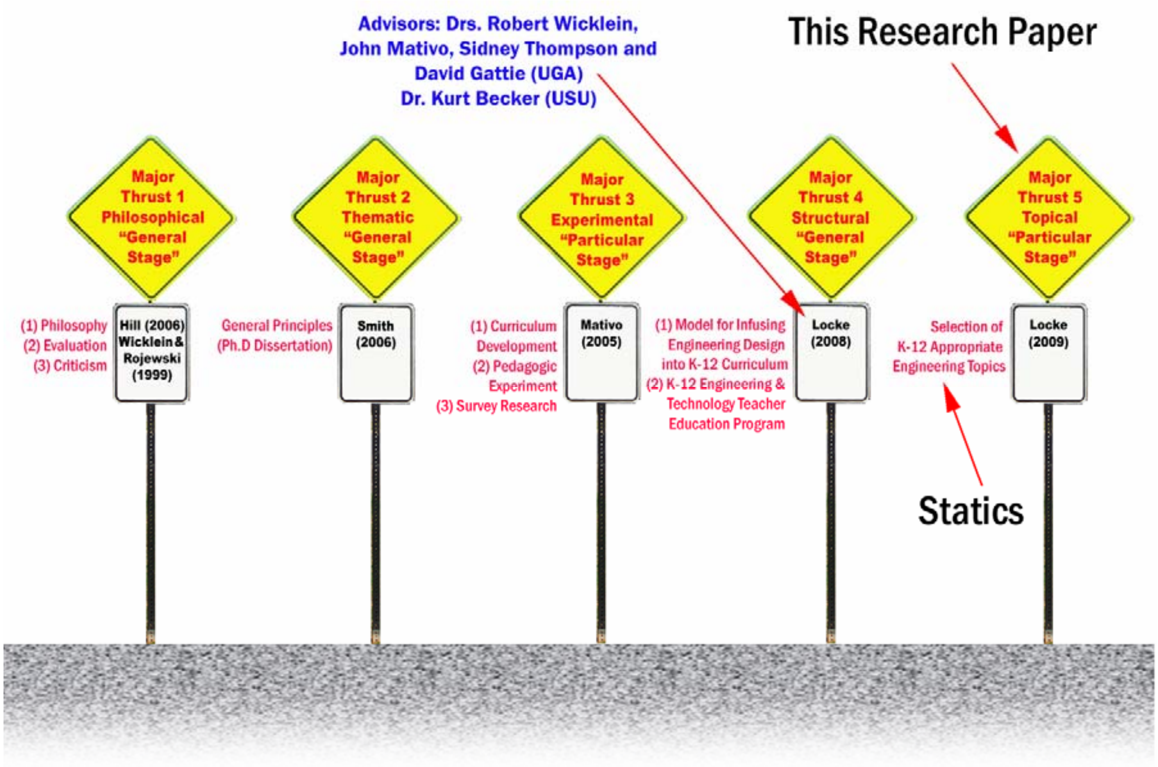

Figure 2. University of Georgia scholars contributions to improving K-12 engineering and technology education.

- <u>1st Major Thrust:</u> Research conducted by Drs. Roger Hill (2006), Robert Wicklein and Jay Rojewski (1999) throughout the recent decades on K-12 technology education, which provides a general analysis of the conditions of K-12 technology curriculum and K-12 technology teacher education at philosophical level, serve as general guidance for subsequent endeavors by graduate students at the University of Georgia. This is a Philosophical "General Stage." During this stage, Wicklein proposed that engineering design should be used as the integrating factor linking mathematics, science, and technology (2008). In my previously presented *Proposed Model for Infusing Engineering Design into K-12 Curriculum*, I decomposed engineering design into two parts: (1) generic design approach; and (2) particular analytic and predictive skills from various subjects of engineering.

- 2nd Major Thrust: The generic principles of engineering, which engineering design experts perceived as important to be incorporated into high school technology education, have been determined by Dr. Cameron Smith's Ph.D dissertation completed under Dr. Wicklein's direction (2006). This is a Thematic "General Stage."
- 3rd Major Thrust: Curriculum development and pedagogic experiments conducted by Dr. Mativo (2005) and other University of Georgia researchers, which built confidence that infusing engineering design into K-12 curriculum is feasible. This is an Experimental "Particular Stage."
- 4th Major Thrust: My previously presented *Proposed Model for Infusing Engineering Design into K-12 Curriculum* (Appendix 1) constitutes a Structural "General Stage," and has analyzed and synthesized the positive achievements of University of Georgia professors and researchers as well as educators across K-12 and collegiate levels in the United States, and other advanced nations (such as Sweden and Finland), and translated the generic principles of engineering determined as important by Dr. Cameron Smith's dissertation (2006) into:
    - Proposed K-12 Engineering and Technology Curriculum: For future generations of American K-12 students, with (1) a Regular K-12 Engineering and Technology Curriculum for all students at all school districts, regardless of race, sex, social-economic status, and academic

disadvantage; and (2) an extracurricular K-12 Engineering and Technology Curriculum Enrichment Program to give higher academic achievers extra opportunities to explore, and to give average and below-average academic achievers an opportunity to review and restudy. This is part of a streamlined K-12 through college engineering education process.

  - Proposed Bachelor of Science in K-12 Engineering and Technology Teacher Program: For the University of Georgia (UGA), the National Center for Engineering and Technology Education (NCETE), and California State University Los Angeles (CSULA).

- 5th Major Thrust: This Research Paper, which constitutes a portion of the Topical "Particular Stage," will assemble a comprehensive set of high school appropriate statics topics with analytic principles and computational skills, for 1 of the 6 engineering analytic courses developed under my previously presented *Proposed Model for Infusing Engineering Design into K-12 Curriculum* (Appendix 1); this will be done on the basis of their pedagogic feasibility in terms of pre-requisite preparation in mathematics and science. This stage includes two major component:
  - Identification of high school appropriate engineering analytic content knowledge: In order for high school students to learn engineering analytic principles and predictive skills, the later must be technically feasible and compatible to high school students' cognitive development level; in other words, high school students must be academically ready, in terms of fulfillment of pre-requisite mathematics, physics and chemistry knowledge

content. Thus, this component will tell us what engineering declarative knowledge content high school students will be ready to learn and at what grade. The major aim of this Research Paper is focused on the subject of statics. Selecting high school appropriate engineering analytic knowledge content on the basis of mathematics, physics and chemistry preparation is in line with the idea of integrative STEM, which has been explored by many scholars and tried in many schools across the United States with varying degrees of success.

- Categorizing of high school appropriate engineering analytic content knowledge into order of importance: What high school students will be ready to learn does not automatically mean that they will have enough energy to proceed. We all know that due to many reasons that are beyond the scope of this Research Paper, K-12 schedules are very crowded; and the academic resources for implementing engineering curriculum are rather limited. Thus, realistically speaking, we can only attempt to infuse the most important engineering analytic content knowledge. To select the most important engineering topics for each subject, a Delphi study with engineering and technology faculty as well as practicing professional will be an appropriate extension to this research.

PART THREE

K-12 STUDENTS' MATHEMATICS & SCIENCE PREPARATION BASED ON GEORGIA PERFORMANCE STANDARDS FOR A POTENTIAL IMPLEMENTATION OF ENGINEERING CURRICULUM

Limitation of This Study

For this Research Paper: This Research Paper is mainly concerned with infusion of engineering analytic content knowledge in the subject of statics, which constitutes one of the foundation courses for university-level engineering majors, or high school "career pathways" under my previously presented *Proposed Model for Infusing Engineering Design into K-12 Curriculum* (Appendix 1).

For this part of the Research Paper: The analysis of K-12 students' preparation of mathematics and science foundation for a potential implementation of engineering design curriculum based on solid analytic knowledge content is applicable to all of the undergraduate engineering programs currently offered at the College of Agricultural and Environmental Sciences, the University of Georgia. These programs share many similar lower-division engineering foundation courses, as illustrated in Table 1. Statics is featured in all of the programs. Table 1 indicates that all programs leading towards the Bachelor of Science in Agricultural Engineering degree feature some or all of the undergraduate lower-division engineering foundation courses. The pre-calculus portions of these courses could be infused into K-12 curriculum.

Table 1
Commonly Shared Undergraduate 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

Georgia Performance Standards (GeorgiaStandards.org, 2009) includes the following sections: (1) English Language Arts & Reading; (2) Mathematics; (3) Science; (4) Social Studies; (5) Health and Physical Education; (6) Modern Languages & Latin;

and (7) Career, Technical, and Agricultural Education (CTAE). Although engineering design is in general a multidisciplinary approach involving all of the above sections, what this Research Paper is concerned with is limited to those that are directly related to the engineering analytic skills at purely technical level. Among all of these sections, the followings are directly relevant to infusion of engineering design into K-12 system: (1) Mathematics, (2) Science; and (3) Career, Technical, and Agricultural Education (CTAE).

Mathematics Preparations

The Role of Mathematics Skills

For a successful infusion of engineering analytic knowledge content into K-12 curriculum at each grade level, relevant pre-requisite mathematics and science (physics and chemistry, as well as related subjects) must be fulfilled at a previous grade level or being fulfilled at the same grade level. Mathematics skills are vital for making analytic computations using formulas, which essentially are symbolic representations of science and engineering analytic and predictive principles. At technical level, the required mastery of mathematics principles, concepts and skills for engineering foundation courses include:

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.

Applied Engineering Mathematics

The most frequently used mathematics skills in practical engineering design are: (1) four operations; (2) geometry and trigonometry; (3) linear algebra; and (4) beginning calculus. All of these skills are covered in most K-12 schools in the United States. Therefore, the current conditions of mathematics education in K-12 systems in the United States are ready for infusion of substantial amount of engineering analytic and predictive principles and computation skills. This point will be explained in the subsequent paragraphs of this part of the research paper.

For the particular subject of engineering statics, mathematics and physics are the relevant pre-requisite items. This part of the Research Paper is aimed at defining K-12 students' completion of mathematics study at various grade levels, under the State of Georgia Performance Standards (GeorgiaStandards.org, 2009).

Selection of Academic Performance Standards

Reasons for the Selection of Georgia Performance Standards for Mathematics: In the United States, there are slight differences among the academic performance standards for K-12 students in different states. In addition, the average academic performance of K-12 students among all schools in all states varies. For convenience, the State of Georgia's Performance Standards, available from the website at https://www.georgiastandards.org/Pages/Default.aspx has been chosen. These standards have been established by the State of Georgia Department of Education on the basis of national performance standards. According to item No. 3 of the *Frequently Asked Questions* link in the website, "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.

According to the Georgia Department of Education website at https://www.georgiastandards.org/Pages/Default.aspx, "The performance standards provide clear expectations for instruction, assessment, and student work. They define the level of work that demonstrates achievement of the standards, […] isolate and identify the skills needed to use the knowledge and skills to problem-solve, reason, communicate, and make connections with other information […] incorporates the content standard, which simply tells the teacher what a student is expected to know (i.e., what concepts he or she is expected to master)." Therefore, these Performance Standards could be 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.

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 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).

Selection of Mathematics Course Sequence Options: *Figure 3* shows the *Math Course Sequence for Grades 6 through 12* under the State of Georgia Performance Standards (GeorgiaStandards.org, 2009). There are 5 Options under the sequence; among these options, Option 2 and Option 3 are established for average (or "middle grade") students. Option 4 seams to be designed for more capable students who could satisfy up to 8th grade GPS in 7th grade. Option 5 is designed for mathematically "highly talented" students. All of these options could lead to AP (Advanced Placement) Calculus course at 12th grade or even 11th grade (for Option 5 only); and this provision allows students to be prepared for engineering analytic courses at undergraduate lower-division level. Notice that under Option 2 and Option 3, the correspondence of Accelerated Math courses to grade levels are as follows: (1) Accelerated Math 1 (Grade 9); (2) Accelerated Math 2 (Grade 10); and (3) Accelerated Math 3 (Grade 11).

An Urgent Need to Increase Domestic Students' Opportunities in Engineering Education

There apparently exists an urgent need to enlarge the horizon of opportunities for average American domestic students to choose engineering as a "doable" and viable career. This statement is based on the facts that (1) the American 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; (2) 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. in engineering programs from India's top engineering programs come to the United States to pursue masters' and doctoral degrees, then 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; and (3) the United States has been in chronic shortage of engineering graduates in the past decades. Thus, at philosophical level, in order to achieve American independence on engineering talent pool, it would be worthwhile to consider 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 as their careers; in fact, many of them will go to management, law, or other non-STEM professions that pay more but require less heavy-duty training in mathematics and science. Thus, relying on the group of mathematically “highly talented” students alone for solving America’s problem of chronic shortage in engineering graduates would not be a safe and realistic option. 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. Since the infusion of engineering analytic content knowledge into K-12 curriculum is proposed for average students, the Options 2 and 3 are used as the basis 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.

Georgia Performance Standards in Mathematics Directly Relevant to the Infusion of Engineering Analytic Content Knowledge throughout the K-12 Curriculum

This part of the Research Paper is concerned with the portions of Georgia Performance Standards for Mathematics, which are relevant to the goal of infusing engineering analytic and predictive principles and computational skills into a viable future K-12 engineering curriculum.

The Georgia Performance Standards website (GeorgiaStandards.org, 2009) states that "the mathematics curriculum is organized into five content strands: number and operations, measurement, geometry, algebra, and data analysis and probability." The Mathematics Performance Standards are organized into the Grade ranges of K-2 (early childhood), 3-5 (elementary school), 6-8 (middle school), and 9-12 (high school), and can be accessed at https://www.georgiastandards.org/Pages/Default.aspx. For Grades K-8, each Performance Standard is established for one Grade level; for Grades 9-12, each Standard is established for all Grades, i.e., 9, 10, 11, and 12, although the various Options of Math Course Sequence (*Figure 3*) divide them into corresponding grade levels. These Math Performance Standards mandate the required mastery of mathematics principles and skills for students at each grade level, and could be used as a reference for determining weather the students at each grade level are ready for learning a particular engineering analytic topic in terms of computational skills. To make their relevance to the infusion of engineering analytic content knowledge into K-12 system more apparent and more convenient to use, these Georgia Mathematics Performance Standards have been reorganized and tabulated into:

- Table 2A (Number, Four Operations & Algebra Topics for Grades K-8): This table indicates that (1) the basics of four arithmetic operations, i.e., addition, subtraction, multiplication and division, are required at Grade 2; (2) the four operations involving decimals, fractions, signs and other numeric elements are required for completion at Grade 7; and (3) the basics of systems of simultaneous equations and inequalities are required at Grade 8 (pp. 29-30).
- Table 2B (Geometry for Grades K-8): The table indicates that (1) the coordinate system, one among the most important constructs for engineering analysis and design, is required at Grade 4; and (2) the characteristics of common two-dimensional figures, such as triangle, square, rectangle, circle, and of three-dimensional solids, such as cone, pyramid, prism, as well as their surface and volume, are required for learning at Grade 8 (pp. 30-31).
- Table 2C (Measurement & Comparison for Grades K-8): The table indicates that (1) the basics of standard units for length, time and temperature are required for completion at Grade 2; and (2) units conversion and units for area and volume are required for completion at Grade 8 (pp. 31-32);
- 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 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 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 2G (Linear Algebra Topics for Grade 10): Linear algebra is among the most important mathematics skill for practical engineering design (p. 34).
- 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 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 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**)

Table 2A (Continued).

Grade	Number, Four Operations & Algebra Topics
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** ↑

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**)

Table 2B (Continued).

Grade	Geometry Topics
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 ↑**

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**)

Table 2C (Continued).

Grade	Measurement & Comparison Topics
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** ↑

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**)

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**)

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**)

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, multiplying, and inverting two-by-two and larger matrices) (**MA2A6**) o 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**) o 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**) o Matrix representations of vertex-edge graphs (**MA2A9**)

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**)

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)	o Number of outcomes related to a given event. (addition and multiplication principles of counting, simple permutations and combinations) (**MA1D1**) o Basic laws of probability (mutually exclusive events; dependent events. conditional probabilities; predicting outcomes) (**MA1D2**) o Relating samples to a population (**MA1D3**) o Variability of data and mean absolute deviation (**MA1D4**) o 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)	o Using sample data to make informal inferences about population means and standard deviations (**MA2D1**) o Create probability histograms of discrete random variables, using both experimental and theoretical probabilities (**MA2D2**) o 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**) o 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)	o The central limit theorem. (**MA3D1**) o Margin of error and confidence interval for a specified level of confidence. (**MA3D2**) o Using confidence intervals and margins of error to make inferences from data about a population. (**MA3D3**)

Science Preparations:

Physics, Chemistry and Materials, Environmental Science and Related Topics

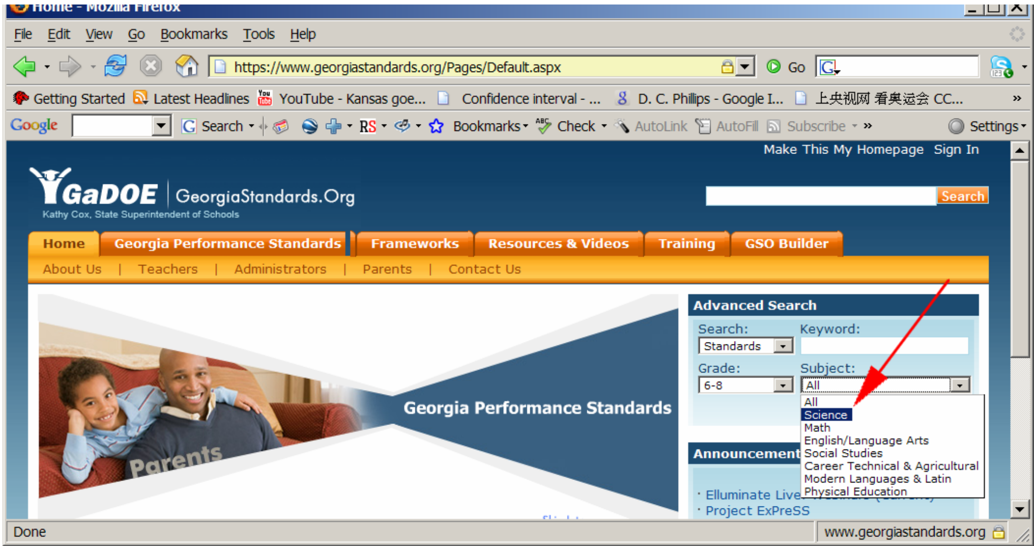

Figure 4A. Website of Georgia Performance Standards for Science (Grades K-8) at https://www.georgiastandards.org/Pages/Default.aspx.

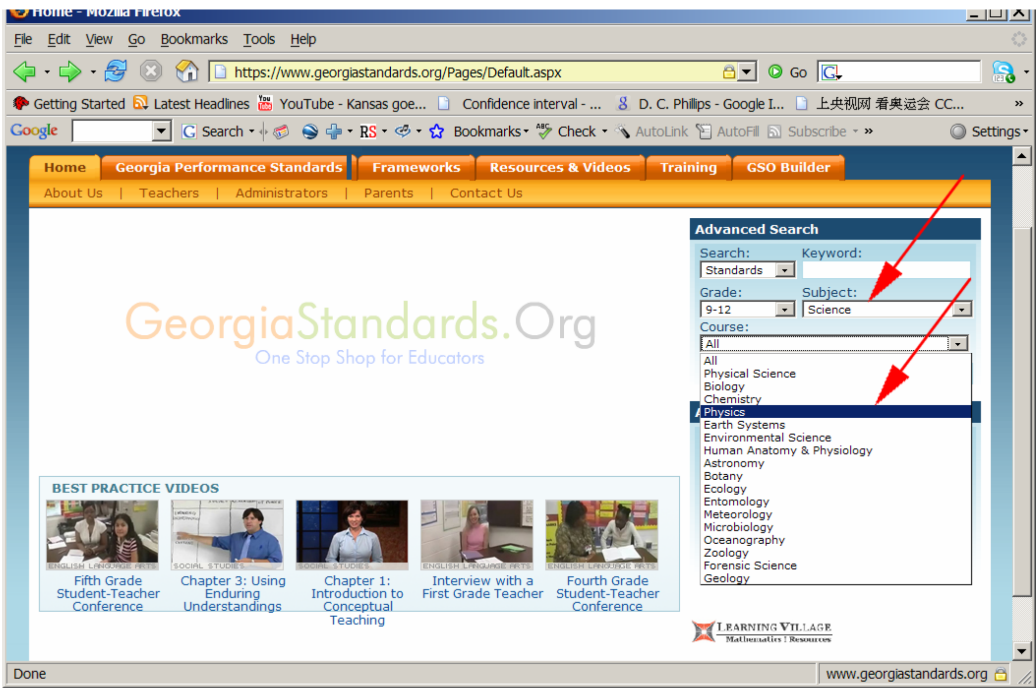

Figure 4B. Website of Georgia Performance Standards for Physics and Chemistry (Grades 9-12) at https://www.georgiastandards.org/Pages/Default.aspx.

Importance of Science Preparation

For a successful infusion of engineering analytic knowledge content into K-12 curriculum at each grade level, relevant pre-requisite scientific principles must be mastered at a previous grade level or being fulfilled at the same grade level. Science concepts and principles are vital for understanding engineering analytic principles. Technically, the required mastery of science principles, concepts and skills necessary for the infusion of engineering analytic and predictive principles include the following categories:

- Physics: Georgia Performance Standards mandates various physics-related content knowledge and problem-solving skills for all grade levels, although 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 include (1) force, (2) energy, (3) rate, and (4) work. The Georgia Performance Standards cover the following content that are tabulated for convenience:
    - Table 3A (Physics-Related Science Topics): These topics are covered in Grades K-8, and classified as "Science" in the Georgia Standards.org website (*Figure 3A*); and 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; as an example, Table 8 in Part Four of this Research Paper (pp. 58-80) indicates that most of the physics concepts and principles needed for learning various topics of statics, such as force,

mass ad acceleration and gravity, are covered in Grades K-8 Science courses (p. 41).

- Table 3B (Physics Topics): "Hard core" high school pre-calculus-level physics are covered at Grades 9-12; and the relevant Performance Standards are listed in Table 3B (Physics Topics) on p. 42. As shown in *Figure 3B*, these standards are written not for a particular grade, but for a range of grades (Grades 9-12). At Clarke Central High School near the University of Georgia, physics courses are offered at Grade 9, 11, and 12 (but not at Grade 10). High school level "hard core" physics courses 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 the topics in these hard core high school physics courses varies, depending on the particular engineering foundation subject. For the subject of statics, as shall be illustrated in Table 8 in Part Four of this Research Paper (pp. 58-80), Newton's Laws (1^{st}, 2^{nd}, 3^{rd}, plus Law of Gravitation) are the only pre-requisites needed.

- Chemistry: Important chemistry content knowledge needed as pre-requisites for engineering curriculum include (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 very important for the subject of material science, fairly important for the subject of fluid mechanics, heat transfer and thermodynamics. For some other subject such as statics and dynamics, its relevance is marginal; therefore, Georgia Performance Standards for Chemistry is not used in the selection of high school appropriate statics topics in this Research Paper. Georgia Performance Standards mandates various chemistry-related content knowledge and problem-solving skills for all grade levels, although the hard core of chemistry education is implemented at Grades 9-12. The Georgia Performance Standards cover the following content that are tabulated for convenience:

- Table 4A (Chemistry and Materials-Related Topics): Table 4A lists all chemistry and material science-related Georgia Performance Standards for Grades K-8, which are selected from those listed under the generic "Science" category, from the same web page where the Physics-Related Science Topics are selected. These standards are written for particular grade levels. They generally provides some basic cognitive background in the 6 important areas of pre-requisite chemistry content knowledge listed at the beginning of the previous paragraph, for the potential implementation of high school appropriate material science, fluid mechanics, heat transfer and thermodynamics curriculum (p. 43).
- Table 4B (Chemistry Topics): Hard core chemistry courses are offered to high school students, at Grades 9-12; the Georgia Performance Standards for Chemistry are established as a single sub-category under the general category of "Science" (*Figure 4B*); and they are written for a range of

grades (for Grades 9, 10, 11, and 12). They provide a solid preparation for college undergraduate engineering programs (p. 44).

- 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, which constitute important factors for socially responsible and ecologically sustainable engineering design, and therefore, should be incorporated as factors for the development of K-12 appropriate engineering curriculum, whenever applicable (notably in the subject of material science). These standards are listed in Table 5 on p. 45.
- General Scientific Approach: As shown in Table 6 (pp. 45-46), 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 3A
Grades K-8 Physics-Related Science Topics Completion Chart
(According to Georgia Performance Standards)

Grade	Physics-Related Science Topics
K	o Different types of motion (straight, zigzag, round and round, back and forth, fast and slow, and motionless) (**SKP2**) → [motion] o Effects of gravity on objects. (**SKP3**) → [gravity]
1	o Weather data and patterns in weather and climate (freezing, melting, precipitation, vaporization) (**S1E1**) o Changes in water as it relates to weather. (**S1E2**) → [state of matter] o Light and sound. (**S1P1**) → [light and sound] o Magnets and effects (**S1P2**) → [natural phenomenon]
2	o Sources and usage of energy (light, heat, and motion) (**S2P2**) → [energy] o Changes in speed and direction using pushes and pulls. (**S2P3**) → [motion]
3	o Production of heat and the effects of heating and cooling, and understanding a change in temperature indicates a change in heat (**S3P1**) → [heat] o Magnets and how they affect other magnets and common objects. (**S3P2**) → [magnetism]
4	o Nature of light (mirrors, lenses, prisms) (**S4P1**) → [light] o Production of sound, vibration of objects and variation of sound by changing the rate of vibration. (**S4P2**) → [sound] o 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	o Electricity, magnetism and their relationship. (**S5P3**) → [electromagnetism]
6	o 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] o 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	o 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**) o 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**) o 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**) o 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**)

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

Grade	Physics Topics
9-12	**<u>Motion and Force</u>:** 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**) **<u>Energy</u>:** 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**) **<u>Electro-magnetic waves:</u>** 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**)

Table 3B (Continued)

Grade	Physics Topics
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**)

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

Grade	Chemistry & Materials Related Topics
K	o Physical attributes of rocks and soils (**SKE2**) → [properties of materials] o 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	o Difference between a physical change (separating mixtures, cutting, tearing, folding paper) and a chemical change (chemical reaction) (**S5P2**) → [chemical and physical changes]
6	o 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] o 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] o 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	o 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]

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

Grade	Chemistry Topics
9-12	**<u>Classified as "Physics:"</u>** 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] **<u>Classified as "Chemistry:"</u>** 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]

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

Grade	Environment Science Topics
3	o Effects of pollution and humans on the environment, protection of environment, conservation of resources, recycling of materials (**S3L2**) → [pollution, conservation and recycling]
5	o 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]

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

Grade	General Scientific Approach Topics
7	o 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**) o 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**) o 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**) o 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**) o 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**) o 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**)

Table 6 (Continued).

Grade	General Scientific Approach Topics
7	o 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**)

Georgia Performance Standards for Engineering and Technology

Characteristics of Georgia Performance Standards in Engineering and Technology

Georgia Performance Standards include, under the general category of "Career, Technical, and Agricultural Education (CTAE)," a section on "Engineering and Technology," as shown in *Figure 4C*. These standards are available from its web page at https://www.georgiastandards.org/Standards/Pp./BrowseStandards/ctae-engineering.aspx.

The Georgia Performance Standards web page indicated that 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."

Figure 4C. Georgia Performance Standards for Engineering and Technology.

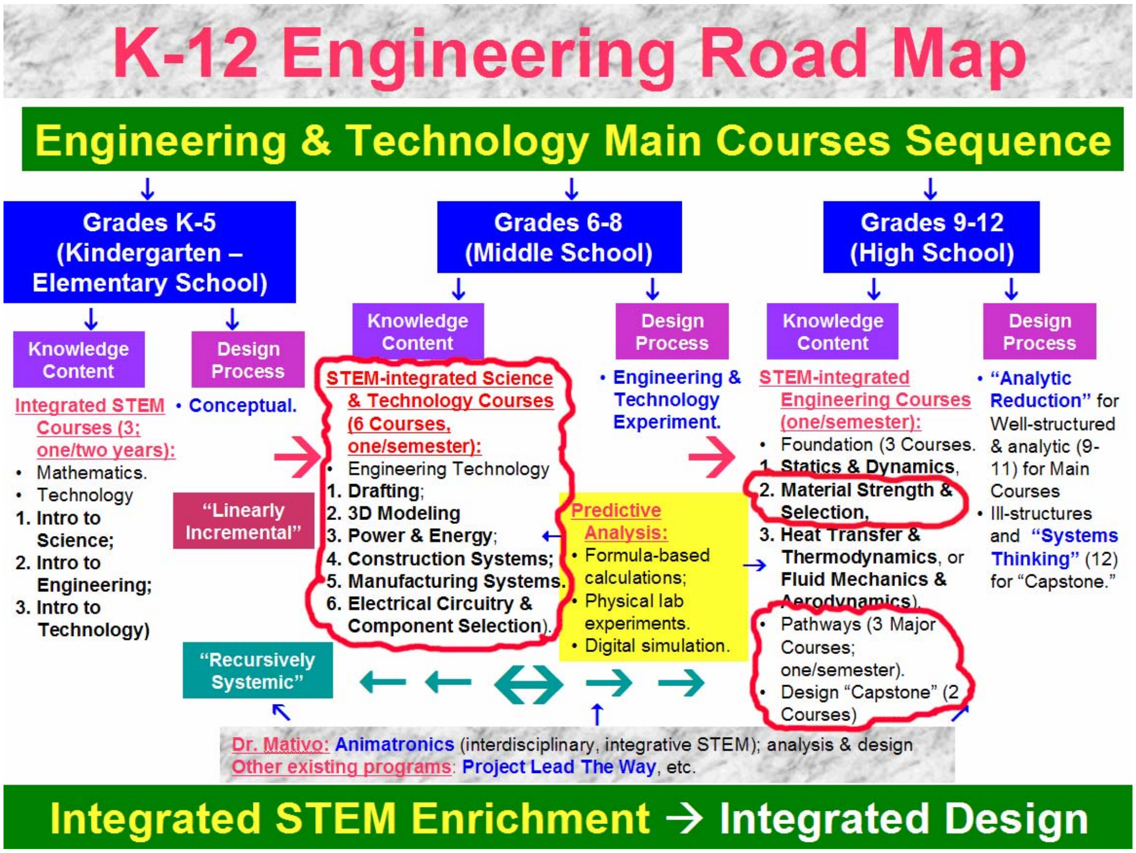

Figure 4D. Proposed Model for Infusing Engineering Design into K-12 Curriculum.

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

A thorough study of the downloaded files under the various categories shown on the right column of the web page (*Figure 4C*) leads to the conclusion that these standards are compatible with the corresponding sections of the K-12 Engineering Road Map (*Figure 4D*) under the *Proposed Model of Infusing Engineering Design into K-12 Curriculum* (Appendix 1): (1) some of the "Engineering Technology" courses for Grades 6-8 (Middle School); (2) some of the "Pathway" and "Design Capstone" courses for Graded 9-11 (High School); and (3) partially with one of the "Foundation" course

(Material Strength and Selection, Grade 9), in terms of the material selection topics.

These courses under the previously presented *Proposed Model* are illustrated in the “K-12 Engineering Road Map” (*Figure 3D*), inside the clouded areas.

Table 7
Georgia Performance Standards for Engineering and Technology - Proposed “K-12 Engineering Road Map 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)

Table 7 (Continued).

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

The mutual compatibilities between these standards and the particular courses in the "K-12 Engineering Road Map" are illustrated in Table 7.

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

<u>Contributions</u>: From Table 7, it is obvious that Georgia Performance Standards for Engineering and Technology makes great contributions to the infusion of engineering design into K-12 curriculum in the following areas: (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). Therefore, these standards could be used as 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: From Table 7, it is obvious that Georgia Performance Standards for Engineering and Technology, except for the materials selection portion of the proposed “Material Strength and Selection” course in the Grades 9-12 (High School), 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. Therefore, these Georgia Performance Standards for Engineering and technology 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.

Summary: This Part of the Research Paper has presented an analysis of relevant Georgia Performance Standards, which shall be used as guidelines and references for the selection of K-12 engineering analytic principles to be infused into the proposed K-12 Engineering and Technology Education Curriculum, for the subject of statics in the Part

Four of this Research Paper, and for all other subject listed in Table 1 (p. 20), after the completion of this Research Paper.

PART FOUR

SELECTION OF HIGH SCHOOL APPROPRIATE ENGINEERING ANALYTIC CONTENT KNOWLEDGE FOR THE SUBJECT OF STATICS

The part of the Research Paper is aimed at:

1. Delineating K-12 students' preparation for learning engineering analytic principles associated with particular subject of statics, in terms of their required mastery of mathematics and science at various grade levels. To be specific, the requirements for academic performance are based on Georgia Performance standards. For the subject of statics, physics is the only relevant subject of science. This delineation is illustrated in Table 8 (pp. 58-80).
2. Presenting a list of K-12 appropriate engineering topics related to the subject of statics, for a five-point Delphi Scale survey study with engineering and technology faculty as well as practicing professionals, in order to further sequence these topics into relevant orders of importance (pp. 81-102).

Selecting High School Appropriate Topics of Engineering Analytic and Predictive Principles and Computational Formulas for the Subject of Statics

Source Materials

As mentioned before, *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), is one of the most popular textbooks used in university undergraduate lower-division statics course, and has been selected as the source of data for the determination of the appropriateness of relevant topics of statics-related analytic and predictive principles and computational formulas for infusion into a potentially viable future K-12 engineering curriculum. The textbook has been browsed and read page by page. All analytic and predictive principles which are symbolically represented by their associated computational formulas, and listed under the title of the relevant chapters, and sub-titles of each of all sections in any particular chapter, have been 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 analytic and predictive principles as well as their associated computational formulas at a particular grade level within the K-12 curriculum.

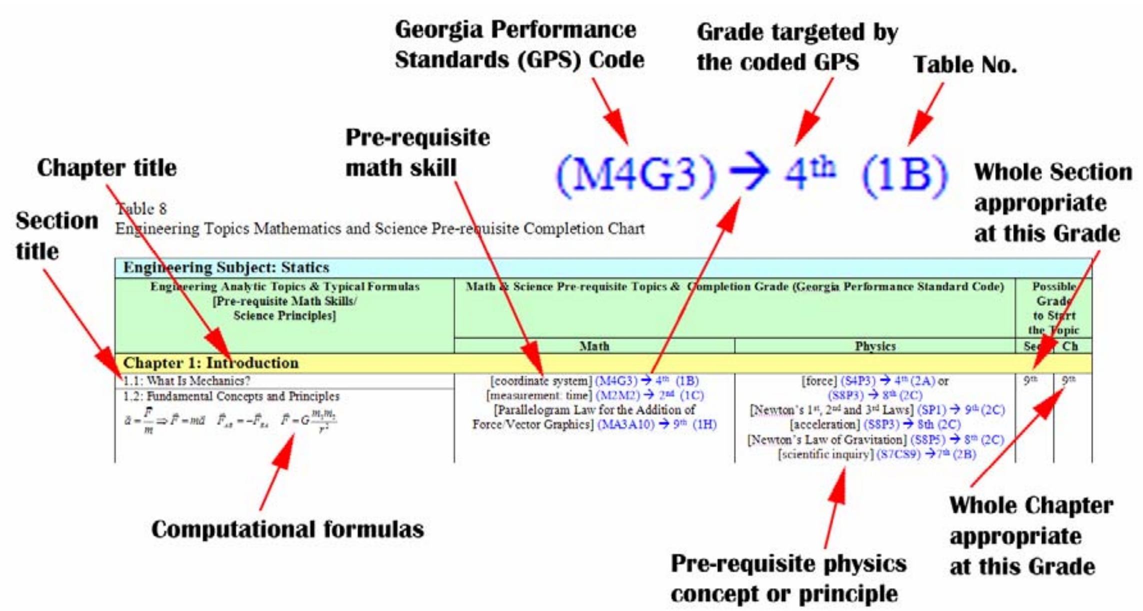

Figure 5. Engineering Topics Mathematics and Science Pre-requisite Completion Chart.

Procedures of Analysis and Selection

<u>1st Step (Defining Mathematics and Physics Pre-requisites)</u>: As shown in *Figure 5*, each of the statics-related engineering pre-requisite mathematics skills and physics

concepts or principles have been defined through careful analysis of their representative computational formulas, and tabulated in the Math and Physics columns of Table 8 (Engineering Topics Mathematics and Science Pre-requisite Completion Chart).

2nd Step (Finding the Earliest Grade of Fulfillment of Mathematics and Physics Pre-requisites): Relevant tables (Tables 2A through 6, pp. 30-47) in Part Three of this Research Paper have been checked to find the earliest grade level where these pre-requisite mathematics and physics are required to be explored at a sufficient depth, according to Georgia Performance Standards, which mandate the academic performance of Georgia's K-12 students.

3rd Step (Recording the Earliest Grade of Fulfillment of Each Mathematics and Physics Pre-requisite): The Georgia Performance Standards Code representing the particular academic performance standard 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); and all of these are typed in blue color.

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 under several sections sharing similar items of mathematics and physics 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.

Adjustment for Mathematically "Highly-Talented" Students

Notice that, as mentioned before, in this Research Paper, 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 (*Figure 3*), which are established for average performing students. As mentioned in Chapter Three, for students enrolled in the Options 4 Math Course Sequence, such determination will still apply. 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.

Criteria for Determination of Grade Level Appropriateness of Statics Topics

The following criteria have been used to determine if a particular topic of statics is appropriate for infusion into high school curriculum, and at which Grade it would be ready for instruction in terms of pre-requisite sequence.

1. <u>Mathematic preparation check</u>: Practically every engineering topic covered in the textbooks used in lower-division undergraduate engineering courses includes mathematically-based formulas or equations, which shall reveal the level of mathematics required for students to comfortably learn the topic's analytic principles and formula-based analytic computation skills. For example, the formula for the calculation of pressure is $\vec{P} \equiv \frac{\vec{F}}{A}$, where $\vec{P}$ is the pressure, $\vec{F}$ is the force exerted on a surface area *A*; this formula involves

division and multiplication as well as calculation of surface area; thus, mathematically speaking, it could be taught only after students master computational skills related to division and multiplication as well as calculation of surface area taught in geometry.

2. Physics preparation check: Practically every engineering topic covered in the statics textbooks used in this Research Paper includes engineering principles that are based on concepts of physics, which shall reveal the knowledge of physics required for students to comfortably learn the topic by thoroughly understanding the underlying principles of physics. For example, the pressure is defined as force exerted per unit area, or $\vec{P} \equiv \frac{\vec{F}}{A}$ where $\vec{P}$ is the pressure and $\vec{F}$ is the force exerted on a surface area A; and the force $\vec{F}$ is defined as mass m multiplied by acceleration $\vec{a}$ in Newton's First Law, or $\vec{F} \equiv m\vec{a}$; thus, Newton's First Law is the pre-requisite principle for high school students to master before the concept of pressure could be comfortably learned. If we want to teach the concept of pressure to students at 9th Grade, then Newton's First Law must either be taught at 8th Grade, or still at 9th Grade but before the concept of pressure is taught, in a correct pre-requisite sequence.