My Four-Stage Curriculum Model for Incorporating Engineering Design Into K-12 Technology Education Programs

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Introduction

The Rationale for Writing This Paper

Background of this paper

Findings and advocacies of established scholars: With regard to integration of engineering design into secondary technology education classes (Grades 6-12), the doctoral dissertation, titled *Identifying Essential Aspects and Related Academic Concepts of an Engineering Design Curriculum in Secondary Technology* (Smith & Wicklein, 2006), written by Phillip Cameron Smith, Jr., under the direction of Dr. Robert C. Wicklein, collected and analyzed opinions from field experts through a four-round Delphi process, and answered the stated *Research Questions* that defined the factors that were considered as important to help secondary students to "understand, manage, and solve technological problems," such as (1) aspects of the engineering design process; (2) mathematics concepts related to engineering design; (3) specific science principles related to engineering design; and (4) specific skills, techniques, and engineering tools related to engineering design (Smith & Wicklein, 2006, p. 4). *Chapter 5* of Smith's dissertation made several important recommendations for future research, which shall be addressed in this paper (Smith & Wicklein, 2006, pp. 83-85), including:

a. Academic content: The participants in Smith's survey research "identified some general areas from mathematics and science that should be included in an engineering design-based curriculum." This paper intends to identify and design courses that could be included in a proposed K-12 Engineering and Technology Teacher Education program, for the University of Georgia, the NCETE, and California State University Los Angeles.

b. Pedagogy: Smith's dissertation indicated that "additional research is needed to determine how to best structure the curriculum in order to emphasize" the skills of "solving open-ended problems, teamwork, and communication," which were identified as very important and as in need of development of instructional methods. This paper intends to define engineering design as the integration of (1) specific analytic knowledge and skills, and (2) generic design processes; and to develop courses and sample units to incorporate both areas, in a coherent, incremental and recursive way throughout the K-12 curriculum, with a "more unified approach" using engineering design as a "curriculum organizer," as recommended by Smith's dissertation.

c. Teacher preparation: According to Smith's dissertation, "This preparation involves at least three things: understanding of the engineering design process, developing the ability to facilitate classroom projects that enable students to engage in engineering design, and gaining the necessary academic skills to do so". The University of Georgia pioneered the efforts at "understanding of the engineering design process" and at "gaining the necessary academic skills" in the current Bachelor's of Science in Education Degree in Career and Technology Education (Technology Education Certificate) program. Dr. Robert Wicklein has incorporated engineering design in many courses such as TETES 7030 - Manufacturing System; and Dr. John Mativo has changed the content of ETES 5090 - Principles of Technology course from physics based on pre-calculus mathematics (which is on the periphery of engineering, or "pre-engineering"), to statics and dynamics based on early calculus mathematics (which are parts of general engineering). This paper intends to continue the endeavors of UGA faculty in the same direction.

My dream: Before joining the National Center for Engineering and Technology Education program as a National Science Foundation Fellow in Fall 2007, under the direction of Dr. Robert Wicklein at the University of Georgia, I started dreaming about a streamlined engineering education system stretching from kindergarten to university undergraduate levels, with pre-calculus level engineering topics taught at high schools and being transferable to undergraduate lower-division credits, for the next generations of engineering students in the United States, for the objective of increasing enrollment of domestic American students in college engineering majors by offering most of them a comprehensive preparation and by giving academically challenged students a better chance to pursue engineering studies as "early birds." Writing this paper gives me an opportunity to systematically and holistically explore the practical issues related to the realization of such dream.

Objective of this paper

The objective of this paper is to propose a four-stage curriculum model for infusing engineering design concepts and activities into a Bachelor's of Science in K-12 Engineering and Technology Teacher Education program, for the University of Georgia and the National Center for Engineering and Technology Education, which could be tailored to the particular needs of any university in the United States (such as California State University, Los Angeles. Refer to Appendix F for details). The model to be proposed is independent from any existing programs (reflecting the idea of "change" which appears to be necessary), but also interdependent with most of the exiting programs (under the proposed model, components from existing programs could be either incorporated into the new model of a regular K-12 Engineering and Technology curriculum, or serve as after-school curriculum enrichment modules); in addition, for the purpose of being practical (reflecting the idea of "continuity" which is a workable philosophy of education), the proposed model will draw reference from:

- The Bachelor's of Science in Education (Technology Education Certificate) program at the College of Education, the University of Georgia (course descriptions are available at http://www.uga.edu/teched/course.htm), as an example of a currently available K-12 engineering and technology teacher education program at university level, with an undergraduate program structure typically used in American public universities;

- The *Career Pathway Program Concentration: Engineering and Technology* published by the State of Georgia Department of Education (available at http://public.doe.k12.ga.us/ci_cta.aspx?PageReq=CICTAEET and http://www.georgiastandards.org/career.aspx), as an example of the emerging expectations for teachers of K-12 engineering and technology programs in the years to come;

- The engineering programs offered at the University of Georgia, as an example of university engineering programs' needs for high school students' pre-engineering preparation.

Dr. Roger Hills' constructive philosophy, Dr. Robert Wicklein and Dr. Jay Rojewski's critical advice for K-12 technology education reform, and potential significance of this paper

Hill (2006) indicated that "initiatives to integrate engineering design within the field of technology education are increasingly evident. Alliances between technology education and engineering were prominent in the development of the Standards for Technological Literacy. […] The history of technology education is replete with trends and changes in curriculum, technical content, instructional materials and equipment, instructional strategies, and even identity. […] A movement to embrace engineering design as a focal element in technology education would be another significant event in the ongoing history of technology education and could become another benchmark in shaping the profession." In addition, he further pointed out that "technology education should retain a general education role, providing hands-on learning activities for all students and encompassing approaches to design and problem-solving that extends beyond engineering to embrace aesthetics and artistic creativity. Engineering design, however, can provide a focus for the field of technology education that is applicable for students in all grade levels and career pathways." The proposed model to be explored in this paper intends to implement these ideas by extensively injecting engineering analysis and design into current K-12 Technology Education and furthermore, re-invent the program as K-12 Engineering and Technology Education, in response to changing societal needs in the Age of Globalization with accelerated technological changes.

Hill (2006) pointed out that "while it would be ideal if technology education teachers mastered mathematics through the first level of calculus, calculus-based physics, and chemistry and studied the principles of statics, dynamics, strength of materials, electronics, and fluids, these levels of mathematics would be problematic for many existing members of the profession as well as for the numerous entry-level teachers participating in graduate level alternative certification programs. […] Implementing an engineering design emphasis in technology education would also require changes in technology teacher education courses" and concluded that "technology teacher educators have much to consider with regard to integrating an engineering design emphasis in technology education. This change of focus represents a major paradigm shift for the profession and has ramifications for curriculum, philosophy, instructional strategies, and collaborative relationships." The proposed new model intends to use Hill's statement as a general guideline and address this issue with practical curriculum restructuring.

Regarding the current conditions of K-12 technology teacher education programs, Dr. Robert Wicklein and Dr. Jay Rojewski offered interesting critical advice. According to Rojewski and Wicklein (1999), "in order to solve technological problems one must develop appropriate intellectual methods and processes. The question of determining what these intellectual processes are is pivotal to developing the unifying curriculum framework for technology education. […] Curriculum that emphasizes technical content tends to be rather short lived and is constantly changing due to the rapid accumulation of knowledge and techniques used in business and industry. In comparison, the mental processes and techniques used in solving technological problems could remain rather consistent over time." The proposed model is focused on (1) an incremental progression of engineering design mental process for regular curriculum, and (2) a recursive one for enrichment program, as a general framework for the proposed curriculum.

Rojewski and Wicklein (1999) further pointed out that "often, curriculum developers in technology education start out to create state-of-the-art instructional activities, only to find that their curriculum materials are out of date soon after they are published. This process has been repeated over and over again with countless state-sponsored curriculum guides and materials. Taxpayers, through local, state, and national departments of education, have contributed millions of dollars over the past 10 years to support the latest forms of technology education within their communities. The learning environments created from these monies usually reflect a narrow type of vocationalism which concentrates primarily on technical skill preparation. This approach requires the curriculum to be constantly in flux, modified in an attempt to incorporate the latest emerging technologies. As a result, both teacher and students experience confusion and inconsistency in program delivery." The proposed model could offer a stable framework for future K-12 Engineering & Technology curriculum, while incorporating state-of-the-art instructional activities.

In addition, Rojewski and Wicklein (1999) indicated that "as a profession, technology educators remain enamored by the gadgetry of technology, with only limited reflection on the deeper educational needs of students. Rather than contribute to helping students develop the higher order thinking skills needed to solve problems within the broad technological aspects of our society, we concentrate on specific technical applications of a few select technologies (e.g., robotics, CAD, desktop publishing, lasers). Students are often left with minor technical skills and an unreflective assumption that all technology is good. Instead of helping students develop a balanced perspective of the impact that technology has on society, we often present it as an independent power in and of itself." The proposed model could (1) focus on all K-12 students' needs for basic engineering and technology literacy (democracy and equality); and (2) Foster critical thinking (appropriate technology and ecological stewardship).

Finally, Rojewski and Wicklein (1999) criticized that "in a sense, technology education might even contribute to the creation of a new form of totalitarianism. The idea of human progress has been replaced by technological progress. Therefore, the new goal of society is to accommodate ourselves to the requirements of technology or, in Postman's (1992) terms, the creation of a "technopoly." The proposed model could help to promote human progress (through appropriate engineering and technology for legitimate human needs as an integral part of curriculum).

The existing K-12 Technology Teacher Education program at the University of Georgia has started moving in this direction with the above-mentioned efforts by Dr. Robert C. Wicklein and Dr. John M. Mativo. The proposed model would add to their endeavors.

Part One

Literature Review

Conclusions from previous scholarly research

Research based on case study in an urban, public, middle school in a slightly below-moderate income neighborhood by Doppelt et al (2008, p. 34) indicated that DBL (Design-Based Learning), instead of "standard, scripted inquiry approach," using the alarm system as an instrument for learning concepts of electrical components and hands-on construction, could allow a wide range of students to improve their understanding of electricity concepts in knowledge tests; and "specifically, these results revealed that African-American and free/reduced lunch students gained significantly more than the other," with "high achievement among African-American and free/reduced lunch students during the lessons;" and therefore, "design-based learning assisted all students and reduced the often-cited achievement gap." According to Doppelt et al, "the observations and the portfolios showed that the low-achievers reached similar levels of understanding scientific concepts despite doing poorly on the pen-and-paper test. […] When the 'freedom to learn' is given to low achievers, they might adjust their learning process and could be more creative. The learner-centered module that was implemented in this study might thus assist them to reach higher levels of achievement. The assessment should capture their creative outcomes and should be sensitive to these achievements." The conclusion shows the benefit of design-based learning. Infusing engineering design into K-12 curriculum would be the focus of this paper.

Smith (2006) discussed various models of infusing engineering content into secondary technology education and pointed out that the problems of "fragmented focus and lack of a clear curriculum framework have been detrimental to the potential of the field and have hindered efforts aimed at achieving the stated goals of technological literacy for all students." The proposed model to be explored in this paper is intended to solve these problems by: (1) synthesizing the strengths of existing models; (2) adding practical details to generic advocacies of experts in the field of technology education; and

(3) proposing some fresh approaches that would help building a coherent and streamlined engineering and technology education process across K-12 and college levels.

According to Meade & Dugger's study published in 2004 (as cited in Smith, 2006, p. 1), "in the United States technology education is part of the state framework for 38 states, there are approximately 35,909 middle or high school technology teachers." Assuming that the figures have not changed significantly from 2004 to 2009, the proposed model explored in this paper shall still make a contribution to K-12 engineering and technology education, in light of recent trends in introducing engineering design concepts in Grades 9-12, as an important part of NCETE agenda (Hailey, Erekson, Becker, & Thomas, 2005, p. 24).

This paper would propose a model of infusing engineering design into K-12 curriculum, which would help future K-12 students to enhance their engineering and technology literacy in a cohesive and systemic way; and to prepare new generations of K-12 engineering and technology teachers to meet the challenges of educating future generations of innovative engineering professionals from K-12 up.

Implementation of scholarly guidelines in the proposed model

As cited in Rhodes and Childress (2006, pp. 50-53), Douglas, Iverson, and Kavandurg (2004) in summarizing the results of an ASEE analysis of current practices in K-12 engineering education, developed some guidelines for the future of K-12 engineering education, which to various degrees are reflected in the construction of the proposed model. These guidelines indicated that engineering education should

1. "Be hands-on in order to motivate students by couching engineering problems in interesting and relevant social contexts." The proposed model intends to structure K-12 appropriate engineering analysis courses in such a way that three hands-on methods are employed to solve engineering analysis problems: (1) Computing with formulas; (2) Using simulation software; and (3) Conducting laboratory experiment.

2. "Be taught in an interdisciplinary approach in order to show the relevancy of mathematics, science, and other subjects, by making engineering a conceptual place for the application of these subjects." The proposed model intends to expand the coverage of "hard-core" engineering analytic knowledge content by developing K-12 appropriate engineering analytic courses, with greater inclusion of engineering principles and formulas based on pre-calculus mathematics, physics and chemistry, in the direction of "integrative STEM" as explored by Sanders (2008).

3. "Develop K-12 standards for use in lesson plans that help teachers teach mathematics and science concepts in the classroom. The proposed model intends to further explore the issue of K-12 engineering and technology standards to accomplish this goal.

4. "Improve teachers by providing […] more professional development, and more curriculum writing." The proposed model intends to drastically but realistically improve the K-12 technology teacher education program, by upgrading it into a well-developed K-12 Engineering and Teacher Education program, for training new generations of competent K-12 engineering and technology teachers in a systemic way.

5. "Make engineering a more attractive career choice for girls and minorities by working with their schools through outreach efforts." The proposed model intends to make learning of engineering analysis and design process more interactive, streamlined and student-friendly, and therefore, providing greater access for disadvantaged students to pursue engineering and technology careers, through a smooth and incremental cognitive and academic flow across K-12 and college levels.

6. "Engage more constituents in partnerships that cross all levels of the educational process." The proposed model intends to serve industry and societal needs under the condition of Globalization that poses greater challenge to America's leading position in engineering innovation, by promoting greater chances of student success in engineering education, through a smoother K-12 to college transition. Such endeavors naturally require more extensive collaboration of teachers, teacher educators, and administrators throughout the K-12 to college institutions; stronger ties among schools, industry, government and civil organizations; and hopefully, such ties would make engineering learning process more meaningful.

Part Two

The Construction of a New Bachelor of Science Degree in K-12 Engineering and Technology Teacher Education as a Logical Extension of the Existing Career and Technology Education Program at the University of Georgia

After comparing the requirements in the UGA teacher training program and State of Georgia Career Pathway and the UGA engineering programs, I found some major discrepancies.

What high schools need for the years to come: The goals of the Georgia Department of Education for K-12 Engineering and Technology Career Pathway

The *Program Concentration: Engineering and Technology* "combines hands-on projects with a rigorous curriculum to prepare students for the most challenging postsecondary engineering and technology programs;" and, unlike the currently available *UGA Bachelor's of Science in Education Degree in Career and Technology Education (Technology Education Certificate) program*, it is clearly divided into four major *Career*

Pathways. Each *Pathway* consists of several courses as listed by the website of Georgia Department of Education, at http://www.georgiastandards.org/career.aspx (all courses to be implemented by Fall 2009. Courses with numbers and * signs are required for the pathway completion). The objectives and courses in each *Career Pathway* are listed in *Table 1*.

Table 1. State of Georgia Career Pathways in Engineering and Technology

Pathway and Objective	**Courses in the Curriculum**
1. Engineering Career Pathway	
Preparing high school students for a general engineering program at collegiate level, without a specific major area.	• Foundations of Engineering and Technology *; • Engineering Concepts *; • Engineering Applications *; • Research, Design, and Project Management; • Engineering Internship.
2. Energy Systems Career Pathway	
Preparing high school students for energy-related engineering and technology program at collegiate level.	• Foundations of Engineering and Technology *; • Energy and Power Technology *; • Appropriate and Alternative Energy Technologies *; • Energy Systems Internship.
3. Electronics Career Pathway	
Preparing high school students for electronics-related engineering and technology program at collegiate level (informatics and engineering, software engineering, mechatronics and robotics, electronics and micro-engineering, computer systems engineering, electrical and electronic engineering and information technology, and telecommunications).	• 21.45200 Foundations of Electronics *; • 21.45300 Advanced AC and DC Circuits *; • Digital Electronics *; • Electronics Internship
4. Manufacturing Career Pathway	
Preparing high school students for modern, CNC-driven manufacturing-related career or higher education at collegiate level.	• Foundations of Manufacturing & Materials Science *; • Robotics and Automatic Systems *; • Production Enterprises *; • Manufacturing Internship.
5. Engineering Graphic and Design	
Appears to be designed for preparing high school student for a career in engineering 2D drafting, 3D modeling and design.	• Introduction to Engineering, Drawing, and Design *; • Engineering Concepts and Drawings *; • Solid Modeling and Design.

How we are preparing our K-12 educators for the years to come: The requirements of UGA Bachelor's of Science in Education Degree in Career and Technology Education (Technology Education Certificate) program

After carefully and critically comparing the State of Georgia Department of Education *Program Concentration: Engineering and Technology* objectives with the current requirements of the UGA Bachelor's of Science in Education Degree in Career and Technology Education (Technology Education Certificate) program, I have made the following two conclusions:

1. <u>Academic knowledge content discrepancy</u>: The current requirements of the UGA program are focused on (1) general pedagogy (in the 15 hours *Teacher Education Requirements* section) and (2) generic topics of technology (in the 46 Hours *Technology Education of Emphasis Requirement* section, and the 3 hours *Major Electives* section), with little inclusion of engineering analytic and predictive content knowledge and of engineering design (which are clearly proposed by the State of Georgia Department of Education's objectives). This discrepancy and my perceived needs for change are illustrated in *Table 2*.

Table 2. Comparison between Georgia DOE High School Career Pathways and B.S. in Education in Career and Technology Education at UGA

Expectations of Georgia DOE High School Career Pathways in Engineering and Technology	**Requirements for B.S. in Education Degree in Career and Technology Education at UGA**
High school students to "be encouraged to take relevant math and science courses, such as advanced algebra, chemistry, calculus, geometry, trigonometry, physics, design, and engineering concepts.	AREA D (Science, Mathematics and Technology) requires only 1 physics course (Phys 1111 & 1111L-Introductory Physics - Mechanics, Waves) and 1 math course (Math 1113-Precalculus), with no requirements for calculus **Perceived need for change**: More math and science courses should to be included
There are several *Career Pathways* under the Engineering and Technology curriculum, including: 1. Engineering Career Pathway, 2. Energy Systems Career Pathway, 3. Electronics Career Pathway, 4. Manufacturing Career Pathway. All of these Pathways have substantial inclusion of engineering knowledge content.	The Technology Education Area of Emphasis Requirements are heavily focused on different fields of technology, with little inclusion of engineering content knowledge (except in ETES 5025-Technical Design Graphics, and ETES 5090 - Principles of Technology). **Perceived need for change**: Options of related engineering courses need to be clearly differentiated and included.

2. <u>Career Pathway differentiation</u>: The State of Georgia Department of Education's Engineering and Technology *Career Pathway* objectives clearly delineated *Engineering and Technology* programs into four different Pathways (see *Table 2*). The current requirements of the UGA Bachelor's of Science in Education Degree in Career and Technology Education (Technology Education Certificate) program do not address this issue of *Career Pathway* differentiation. This discrepancy and recommendations for change have been illustrated in *Table 1*.

The pre-engineering preparation of high school students needed for a smooth transition into University undergraduate engineering programs

The University of Georgia *Engineering Academic Programs* currently offer Bachelor of Science in the following majors: (1) Agricultural Engineering (including Mechanical, Electrical and Civil Engineering options); (2) Biochemical Engineering; (3) Biological Engineering; (4) Environmental Engineering; and (5) Computer Systems Engineering (both software and hardware). By comparing these programs with the K-12 *Career Pathways in Engineering and Technology* defined by the Stare of Georgia Department of Education, we can see a gap between the two, as illustrated in *Table 3*.

The above comparisons show that currently, in the United States, there are gaps among the following three major components in engineering and technology education across K-12 and university levels, which are graphically illustrated in *Figure 1*:

- Engineering and technology education for K-12 students;
- K-12 engineering and technology teacher education programs;
- University engineering programs.

Rationale for infusing engineering design into technology curriculum: Bridging the gaps among k-12 engineering and technology curriculum, teacher education, and university engineering majors

Wicklein (2006, p. 29) indicated that in the United States, "currently, engineering education has close to a 50% attrition rate for students. […] Georgia currently seeks 50% of the engineering workforce from out-of-state sources." This statement reflects a generally agreed shortage of domestic engineering graduates in the United States. Therefore, although we can not expect that all high school graduates from engineering and technology *Career Pathways* will enroll in engineering and technology programs at universities (some of them will end up enrolling in non-engineering majors while others will end schooling and enter job market), we should design our new K-12 engineering and technology teacher education program with a reasonable expectation that the future teachers' primary mission is to prepare high school students for majors in engineering at university level.

Closing these gaps will promote a smoother and more "streamlined" transition for high school graduates to enroll in university engineering programs, or pursue other careers with an experience in creative design. With advice from Dr. Wicklein (2008, advisory meeting), I have concluded that our efforts should be focused on improving the high school engineering and technology teacher education programs for the time being, since the existing programs do not adequately prepare future teachers for the challenges ahead; and the key to this improvement is the inclusion of engineering design into existing high school engineering and technology teacher education programs.

Wicklein (2006, p. 25) proposed design as the integrating factor linking engineering and science through high school technology program; identified and explained some important rationale for having the field of technology education direct its focus on engineering design, including: (A). Engineering design provides an ideal platform for integrating mathematics, science, and technology, requiring the linkage of narrative discussion/description, graphical explanations, analytical calculations, and physical creation; and (B). Engineering provides a focused curriculum that can lead to multiple career pathways for students.

Table 3. Comparison between Georgia DOE High School Career Pathways Program and Engineering Programs at UGA

Georgia DOE High School Career Pathways Program in Engineering and Technology	**Engineering Programs at UGA**
Georgia DOE High School Career Pathways Program in Engineering and Technology prepares high school students in the following Career Pathways: • Engineering Career Pathway; • Energy Systems Career Pathway; • Electronics Career Pathway; • Manufacturing Career Pathway; • Engineering Graphic and Design.	Engineering Programs at UGA needs entering students to be prepared for the following majors: • Mechanical, Electrical and Civil Engineering; • Biochemical Engineering; • Biological Engineering; • Environmental Engineering; • Computer Systems Engineering (both software and hardware). **Perceived need for change**: New *Career Pathways* could be developed and added to the Georgia program in Engineering and Technology to better prepare high school students for college engineering programs.

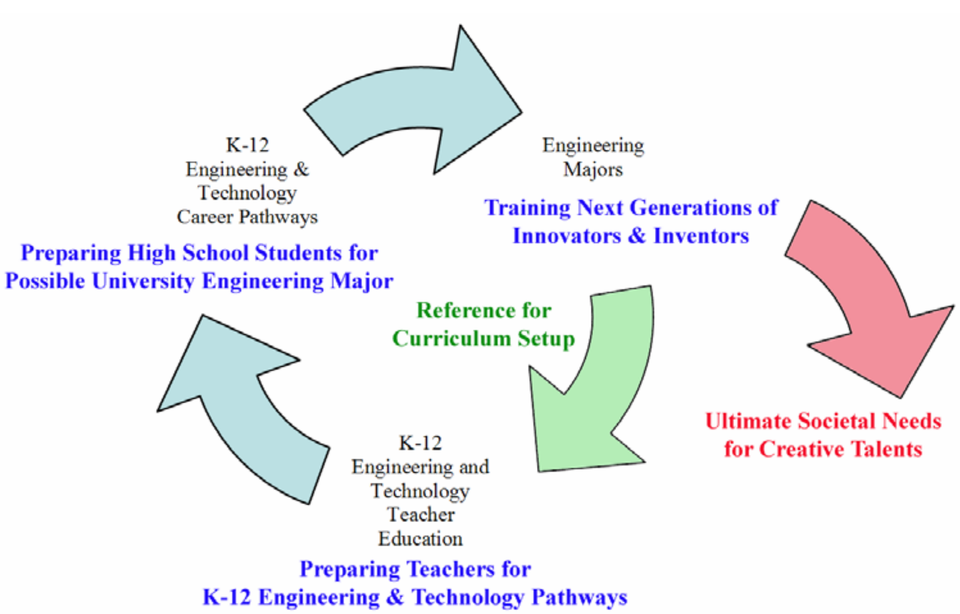


Figure 1. Relationship among the three components in the K-12 through university engineering and technology cycle.

Table 4. Proposed new B.S. in Education Degree in K-12 Engineering and Technology Teacher Education for the College of Education, University of Georgia

GENERAL CORE COURSES	
Area A - Essential Skills - 9 Hours	
English – 6 Hours	
ENGL 1101 - English Composition I	3 hrs
ENGL 1102 - English Composition II	3 hrs
Math – 3 Hours	
Math 1113 - Precalculus	3 hrs
Area B – Institutional Options – 4-5 Hours	
No change from existing program.	4-5 hrs
Area C – Humanities/Fine Arts – 6 Hours	
No change from existing program.	6 hrs
Area D – Science, Mathematics and Technology – 23 Hours	
Math – 11 Hours	
Math 2250 - Calculus I for Science and Engineering (Differentiation)	4 hrs
Math 2260 - Calculus II for Science and Engineering (Integration)	4 hrs
Math 3000 - Introduction to Linear Algebra	3 hrs
Physics – 8 Hours	
Physics 1111-1111L - Introductory Physics (Mechanics, Waves, Thermodynamics)	4 hrs
Physics 1112-1112L - Introductory Physics (Electricity and Magnetism, Optics, Modern Physics)	4 hrs
Chemistry – 4 Hours	
Chemistry 1211-1211L - Freshman Chemistry I and Lab	4 hrs
Area E – Social Sciences - 12 Hours	
No change from existing program.	12 hrs
Area F Course Related to Major – 10 Hours	
EDUC 2120 - Exploring Socio-Cultural Perspectives on Diversity	4 hrs
EPSY 2130 - Exploring Learning and Teaching	3 hrs
EDIT 2000 - Computing for Teachers	3 hrs
Basic Physical Education	1 hr
Total General Core Hours	**68-69 hrs**

Table 4. (Continued)

College of Education Requirements

The K-12 Engineering and Technology Teacher Education Requirements – 15 Hours

EOCS 2450 – Practicum in K-12 Engineering and Technology	I	1 hr
EOCS 3450 – Practicum in K-12 Engineering and Technology	II	2 hrs
ENGR 1920 - Introduction to Engineering		2 hrs
EOCS 4350 - Curriculum Planning in K-12 Engineering and Technology Studies		3 hrs
EOCS 2450 – Instructional Strategies in K-12 Engineering and Technology Studies		3 hrs
EOCS 5550 Students w/ Special Needs in Progr. of Occupational Studies		3 hrs
Total Teacher Education Hours		**14 hrs**

K-12 Engineering and Technology Education Area of Emphasis Requirements – 54 Hours

Foundation Engineering and Technology Requirements – 36 Hours

Engineering and Technology – 30 Hours

ETES 5010&5100 - Appropriate Engineering & Technology in Society	4 hrs
ETES 5020A - Technical Design Graphics: 2D Drafting	3 hrs
ETES 5060 - Energy Systems	3 hrs
ETES 5070 - Research and Experimentation in Technological Studies	3 hrs
ETES 5090A - Principles of Technology I: Statics and Dynamics	4 hrs
ETES 5090B - Principles of Technology II: Material Strength and Selection	4 hrs
ETES 5040 - Construction Systems	3 hrs
ENGR 2110 - Engineering Decision Making	3 hrs
ETES 5140/7140 - Laboratory Planning, Management, and Safety	3 hrs

Engineering and Technology Curriculum Development – 6 Hours

ETES 5020 - Communication Systems	3 hrs
ETES 2320 - Creative Activities for Engineering Technology Teachers	3 hrs
ETES 2320B - Digital Simulation for K-12 Engineering & Technology	3 hrs

Engineering Analysis and Technology Options: - 9-12 Hours

Additional options could be developed according to needs. Each student is required to choose one Option of 3 courses from the following:

Mechanical Design Option - 12 Hours

ETES 5020B - Technical Design Graphics: 3D Solid Modeling and Design	3 hrs
ETES 5090C - Principles of Technology III: Fluid Mechanics & Aerodynamics	3 hrs
ETES 5090D - Principles of Technology IV: Heat Transfer & Thermodynamics	3 hrs

Table 4. (Continued)

MAJOR COURSES (Continued)	
ETES 5090E - Mechanism Design & Selection	3 hrs
Manufacturing System Option - 9 Hours	
ETES 5030/7030 - Manufacturing Systems	3 hrs
ETES 5090F - Robotics and Automatic Systems	3 hrs
ETES 5090G - Production Enterprises	3 hrs
Electrical and Electronics Option - 9 Hours	
ETES 5090H - Electronics Circuitry & Component Selection	3 hrs
ETES 5090I - Advanced AC and DC Circuits	3 hrs
ETES 5090J - Digital Electronics	3 hrs
Capstone Engineering Design Courses – 6 Hours	
ETES 5110A/7110A - Engineering Design I	3 hrs
ETES 5110B/7110B - Engineering Design II	3 hrs
K-12 Engineering and Technology Education Area of Emphasis Subtotal	**57 hrs**
TOTAL SEMESTER HOURS REQUIRED FOR GRADUATION	**133-132 HOURS**

Note:
Under the proposed program, the total number of science, engineering analysis and design courses is 22; and the total semester hours is 74 (57% of the total semester hours required for graduation):

Total General Core Hours (Except Math and Science)		**42-43 Hours**
Area D – Science, Mathematics and Technology	**7 Course**	**26 Hours**
K-12 Engineering and Technology Education Area of Emphasis Requirements	**17 Courses**	**54 Hours**
Total Credit Hours for Graduation:		**122-123 Hours**

Table 4 above illustrates the proposed model. The construction of the proposed model shall be explained as follows.

Basic components of a practical model for infusing engineering design into K-12 engineering and technology teacher education program at university level

1. Engineering design: Lewis proposed “to approach analytic design in a limited way by including a set of completely worked out engineering design cases in the instructional repertoire of schools” (2005, p. 49). Wicklein (2006, p. 29) pointed out that “university programs that prepare technology teachers will be required to change their programs to address the needs associated with engineering design. A primary need that must be addressed in technology teacher education programs will be the elevated mathematics and science requirements necessary to teach subjects such as engineering design and engineering applications. […] Serious reviews and changes of existing teacher

education curriculum must be conducted if an engineering focus is to be attained and implemented at the high school level." These statements point to the need for engineering design as an important part of technology teacher education.

2. Engineering analytic and predictive course content: Without knowledge and skills acquired from different subjects of engineering, K-12 engineering design curriculum, as well as K-12 engineering and technology teacher education program preparing qualified teachers for such curriculum, will hardly move beyond conceptual design stage and "trial-and-error" type of traditional "technology education design process." A fundamental shortcoming of many currently fashionable Project-Based Learning high school engineering curriculum is playing with technology without systematically learning the fundamental principles of engineering behind it. For example, high school students might play with assembling and programming simple robotics, which is entertaining; but without learning the fundamental principles of mechanical engineering, electronics and computer science, the skills and knowledge gained from this type of educational entertainment could not be broadly generalized to benefit students in later careers. Mativo believed that the current B.S. in Education in Career and Technology Education program at UGA should be re-designed to acquire an attribute of a "general engineering" program (personal conversation, December 17, 2008). Regarding how to overcome the critical shortcomings of the current practices in K-12 technology education and to establish engineering education as a strong subject in K-12 systems, Lewis (2007, p. 846-848) discussed the need to: (1). 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); (2). make engineering education a coherent system with the creation of content standards for the subject area, in line with science and technology education.

The above scholarly advices point to the need to systematically incorporate particular engineering analytic course content, as well as generic engineering design methodologies, into K-12 technology curriculum; and they provide insights for my proposed model for infusing engineering design into K-12 technology teacher education programs at university level, which is illustrated in *Figure 2*, and include the following three components:

1. Basic engineering analysis courses: These courses will build a solid foundation on engineering analytic and predictive principles, concepts and methods (ideally including a. pen-and-pencil calculations using mathematics-based formulas; b. digital simulation; and c. physical laboratory experiment). In these courses, a final project for applying engineering principles taught in the course in a simple engineering design should be required, in addition to the coverage of regular course topics (under the sections of Engineering and Technology and of Engineering Analysis and Technology Options in the proposed program, in *Table 4* and *Table 8*). These courses should have the following attributes:

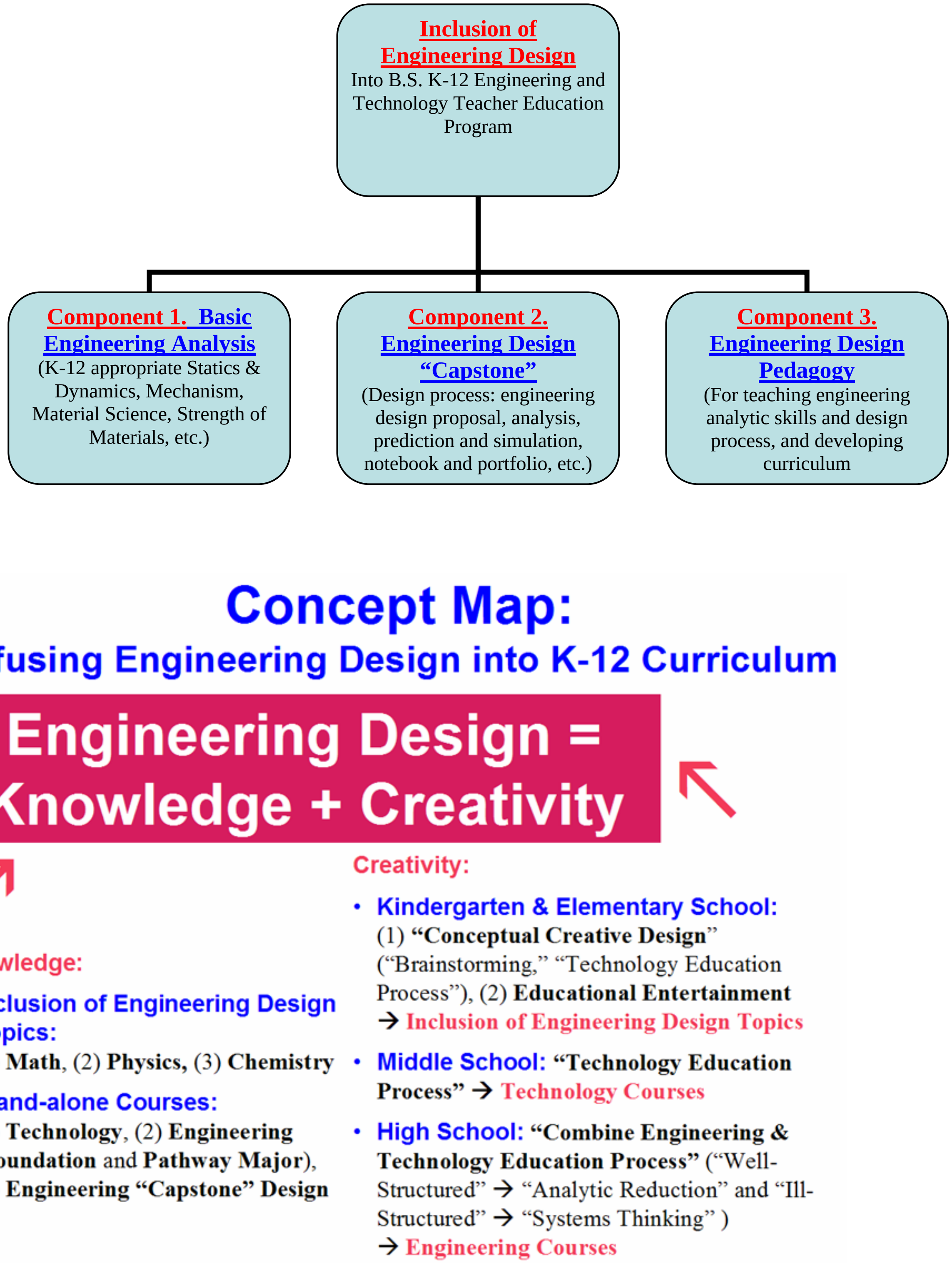


Figure 2. *The three components for including engineering design into K-12 engineering and technology teacher education programs, and "concept map" for infusing engineering design into K-12 engineering and technology education.*

- Curricular organization: Be organized into clearly differentiated options of related courses, which correspond to high school engineering and technology *Career Pathways* and to the most important engineering majors at university level; for example, there could be a Mechanical Engineering Option that include courses such as Mechanism Design, Materials Strength and Selection, Statics and Dynamics, and Manufacturing, etc. Doing so would allow future generations of K-12 engineering and technology teachers to possess more specialized expertise in relevant subject matter, rather than just general knowledge about a variety of technologies.

- Relations with regular engineering courses: Be to some degree a "light but condensed version" of typical university undergraduate engineering courses, with a focus on the practical side of engineering design. For example, in the Fall 2008, Dr. John Mativo taught selected topics of statics and dynamics in the ETES 5090 - Principles of Technology course to Career and Technology Education students at UGA; he selected high school suitable topics of statics and dynamics for coverage, from two regular engineering courses. In my opinion, our principal mission should not be to train engineers working in industry, but rather to train teachers with adequate qualifications to teach K-12 students engineering and technology, including engineering analysis, prediction and design. The future generations of K-12 engineering and technology teachers should not be expected to design rockets and space ships (which is the job of engineers); however, they should be able to design simple products and systems, and to teach engineering design to K-12 students with appropriate pedagogy (which is the job of K-12 engineering and technology teachers).

- Limitation on mathematic requirements: Be mathematically restricted to trigonometry, geometry, algebra including linear algebra and beginning calculus (integration and differentiation, up to three-dimensions). This is the levels of mathematics that are frequently required in actual professional engineering practice; and they are the highest levels of mathematics that average academically successful high school students could possibly reach.

2. "Capstone" engineering design courses: These courses should prepare future K-12 engineering and technology teachers for solving practical engineering design problems, by using knowledge and skills gained in the basic engineering analysis courses (component 1). These courses should be set up in similar ways as typical senior design courses in undergraduate engineering programs. In these courses, the future K-12 engineering and technology teachers should be well trained for strategy and processes in analyzing problems (both well-structured and ill-structured), and in solving problems with innovative design (both conceptual and analytic), using a combined

engineering and technology design process, which is illustrated in *Figure 3*. One of the expected outcome of these courses should be the assembly of a professional portfolio that demonstrate the following abilities to represent engineering design:

- Semantic: Using word-processor (such as Microsoft Word), presentation software (such as PowerPoint), and engineering notebook for verbal or textual explanation and definition of the problem;

- Graphical: Using pen-and-pencil sketches and 3D CAD programs (such as SolidWorks, Autodesk Inventor, etc.) to create technical drawings of an object or a system, with engineering notebooks and printouts;

- Analytical: Using mathematical equations in predicting solutions to technological problems, and/or digital simulation programs (such as SolidWorks, Electronic Workbench, and others) in testing engineering design before building a physical prototype;

- Physical: Constructing technological artifacts or physical models for testing, analysis and presentation.

3. Engineering design pedagogy courses: These courses should prepare future K-12 engineering and technology teachers to

   - Teach particular engineering analytic knowledge content, as well as generic engineering and technology design principles (see *Figure 3*); and

   - Design relevant teaching and learning materials for K-12 engineering and technology programs, and implement relevant curriculum with appropriate pedagogy.

These courses are featured in the "K-12 Engineering and technology Teacher Education Requirements" section and "Engineering and Technology Curriculum Development" sub-section of the proposed model (see *Tables 4* and *8*).

Technology Education Design Process	**Combined Engineering and Technology Design Process** (Edward Locke)	**Engineering Design Process**
❑ Defining a Problem →	❑ **Defining a Problem and/or Identify the Need for a Solution**	← ❑ Identify the Need
❑ Brainstorming →	❑ **Researching Existing Solutions in the Market or Community** (Local, National, and International) Through Visitation and/or Internet Search, Analyzing Their Strengths and Shortcomings for a Possible Better Solution	← ❑ Define Problem
❑ Researching and Generating Ideas →	❑ **Generating Ideas** Through 3-4-5 Brainstorming Sessions for Better Solutions Incorporating Various Strengths of Existing Products/Systems Plus Innovative Features	← ❑ Search for Solutions
❑ Identifying Criteria →	❑ **Identifying and Specifying Criteria and Constraints for New Design**	← ❑ Identify Constraints
❑ Specifying Constraints →		← ❑ Specify Evaluation Criteria
❑ Exploring Possibilities →	❑ **Comparing and Evaluating Solution Ideas** from Brainstorming Sessions Against the Established Criteria and Constraints	← ❑ Generate Alternative Solutions
❑ Selecting an Approach and Develop a Design Proposal →	❑ **Initial Decision-Making:** Selecting the Most Suitable Approach to Solution and Developing a Design Proposal Based on Analysis of Engineering Design Factors	← ❑ Engineering Analysis
❑ Building a Model or Prototype → ❑ Testing and Evaluating the Design → ❑ Refining the Design →	❑ **Mathematical Predictions and Digital Simulation If Possible** ❑ **Final Decision Making and Design Specifications** ❑ **Building a Model or Prototype** ❑ **Testing and Evaluating the Design** ❑ **Refining the Design**	← ❑ Mathematical Predictions ← ❑ Decision Making ← ❑ Design Specifications
❑ Communicating Results →	❑ **Communicating Results** with CAD 3D Models and 2D Drawings	← ❑ Communication

Figure 3. My Combined Engineering and Technology Design Process, its integration into the K-12 Engineering Design Process adapted by NCETE, and the model of teaching.

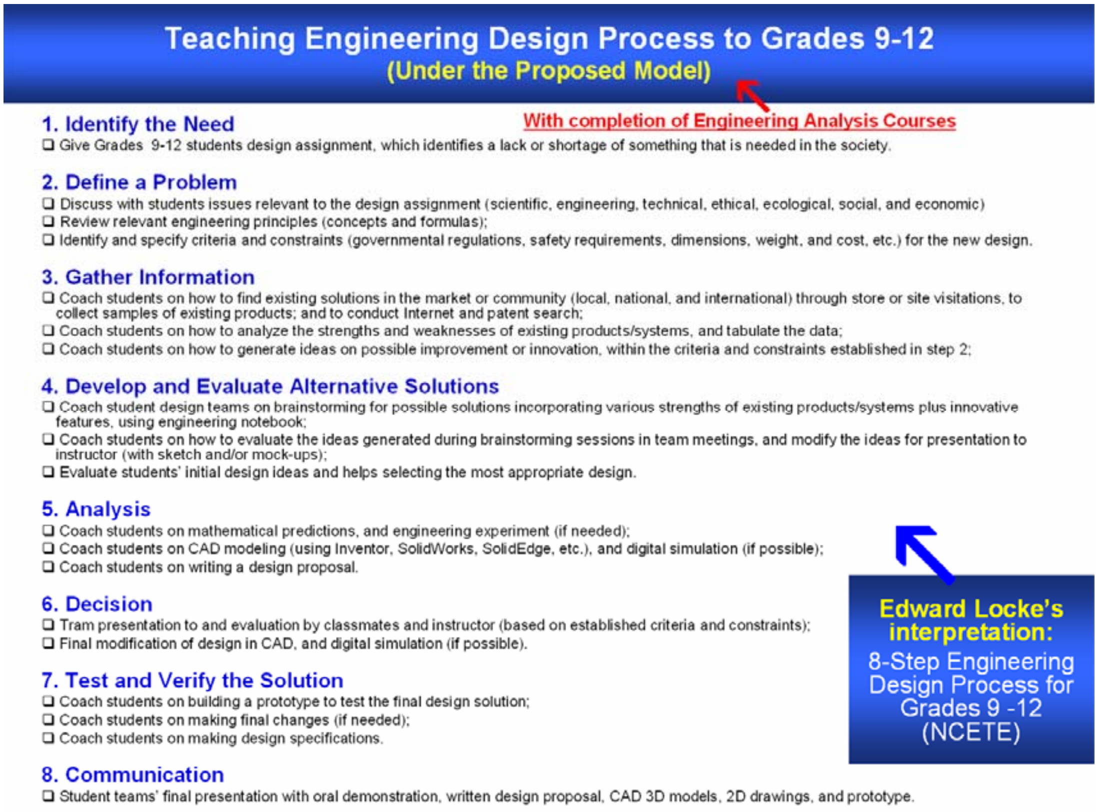


Figure 3. Continued.

A practical need for change

As discussed in the previous sections, using the requirements of the State of Georgia Department *Career Pathways* in Engineering and Technology as an example of emerging expectations for K-12 engineering and technology teachers, and the current B.S. in Career and Technology Education at UGA as an example of available K-12 engineering and technology teacher education programs, I have shown major discrepancies between the two. The major problem might be that too many credit hours are consumed by "General Core" (Areas A through F, 61 credit hours, or 50% out of a total of 120 credit hours) and by "Teacher Education Requirements" (15 credit hours, or 12.5%), leaving too little space for "Technology Education Area of Emphasis Requirements" (only 46 credit hours, or 38%) and "Major Elective" courses (only 3 hours, or 2.5%). It is obvious that graduates from the existing program with be well versed in the social aspects of teaching (after taking a total of 76 credit hours, or 63% of total required credit hours), but will be short on knowledge and skills related to science, engineering and technology (after taking only 49 credit hours, or merely 40% of total required credit hours). Thus, changes could be made to update the existing program to near future needs, in terms of increasing credit hours for knowledge and skills related to science, engineering and technology, while condensing or remodeling the social and pedagogic portion of the requirements. This could be accomplished within the existing general framework of undergraduate program structure.

Under the above proposed program, the future teachers will acquire adequate ability to conduct and teach analysis-based engineering design to K-12 students. Thus, engineering design is thoroughly incorporated into the existing B.S. in Education Degree in Career and Technology Education at UGA. The proposed program should allow graduates to implement the State of Georgia Department of Education K-12 Engineering and Technology *Career Pathway*.

The proposed program as a modified version of the existing program at UGA

Similar to any undergraduate program in American public universities, the overall structure of the proposed K-12 Engineering and Technology Teacher program will include the following two major component: (1) “General Core” courses; (2) “Major” courses (further categorized into “K-12 Engineering and Technology Teacher Education”, and “K-12 Engineering and Technology Education Area of Emphasis” sub-sections), as illustrated in *Table 4*. This proposed program is based on (1) a moderate modification of the Areas A through E (the “General Core”) of the existing UGA B.S. program; (2) a moderate to substantial change of its “Teacher Education Requirements” courses; and (3) a substantial change of its “Technology Education Area of Emphasis Requirements” and its “Major Electives” courses. The changes are explained as follows:

<u>1. “General Core” courses</u>: The proposed program would include modifications that would make the “General Core” component more relevant to the needs of K-12 engineering and technology teacher education, which are explained as follows:

<u>Area A (Essential Skills)-Mathematics:</u> In this areas, it could be perceived the Math 1101 (Introduction to Mathematical Modeling) not to be so relevant to the proposed program (based on my understanding of the needs for a practical engineering program, such as those required at California State University Los Angeles, a non-research university); and I therefore proposed its replacement by Math 1113 (Precalculus), which would be removed from <u>Area D</u>.

<u>Area D (Science, Mathematics and Technology)-Mathematics:</u> Substantial modifications could be made in this Area. Besides removing the existing Math 1113 (Precalculus), additional mathematics and science course would be added: (1) Math 2250 (Calculus I for Science and Engineering, 4 hours. Prerequisite: Math 1113. This course covers differentiation), Math 2260 (Calculus II for Science and Engineering, 4 hours. Prerequisite: Math 2250. This course covers integration); (2) Math 3000 (Introduction to Linear Algebra, 3 hours. Prerequisite: Math 2260); (3) Physics 1112-1112L (Introductory Physics-Electricity and Magnetism, Optics, Modern Physics. 4 hours); (4) Chemistry 1211-1211L (Freshman Chemistry I and Lab. 4 hours. Prerequisite: Math 1113-Precalculus). It is noticeable that Math 2250 and 2260 as well as Chemistry 1211-1211L courses are the same as the ones required by the UGA undergraduate engineering program (B.S. in Agricultural Engineering, for Mechanical, Electrical and Electronics majors). The Physics 1112-1112L course continues the sequence in physics after the Physics 1111-1111L which is already required in Area D. All of the above will increase the number of credit hours from 10-11 hours to 20 hours. These courses would build an

adequate foundation in science (up to early calculus), for future K-12 engineering and technology teachers.

Area F (Course Related to Major – 18 Hours): In this Area, the 6-hour "Electives Related to the Major" will be transferred to Area D to offset part of the 10-11 hour increase. In addition, from the descriptions of the courses available online at http://www.googlesyndicatedsearch.com/u/universityofgeorgia?hl=en&domains=uga.edu&ie=ISO-8859-1&q=Course+Listing+for+EDUC+&btnG=Search&sitesearch=uga.edu, EFND 2110 (Investigating Critical and Contemporary Issues in Education, 3 hours) and EDUC 2120 (Exploring Socio-Cultural Perspectives on Diversity, 3 hours) courses are basically covering the same topic of cultural diversity in education, and thus, could be combined into one 4-hour course. This will free up 2 hours to offset part of the 10-11 hour increase in Area D. The alternative would be to keep both courses separate and thus allow the total credit hours for graduation to increase further.

2. The Teacher Education Requirements: All courses will be retained but the course content could be modified to focus on engineering design and technology-related pedagogy, with modified descriptions of courses, selection of course content and textbook, etc. The word "Occupational" in the course titles would be changed to "Engineering and Technology." Refer to Appendix C for proposed new course descriptions.

3. Technology Education Area of Emphasis Requirements: The name of the area would be changed to "Engineering and Technology Education Area of Emphasis Requirements." This would be the area for implementing the inclusion of engineering design into the K-12 engineering and technology teacher education program, in terms of the above-mentioned "basic engineering analysis" and "capstone engineering design" courses. Major changes could be proposed to make the program less generalist and more specialist, by creating well-structured options of courses corresponding to engineering majors at the University of Georgia, and to *Career Pathways* prescribed by the State of Georgia Department of Education for the new K-12 engineering and technology curriculum in Georgia's school districts; this would allow future K-12 engineering and technology teachers to possess greater expertise in particular fields of engineering and technology, in terms of mastery of engineering analytic and predictive principles, concepts and computational skills.

Under the proposed model, the area could be divided into three sub-sections:

1. Foundation Engineering and Technology Requirements: Courses under this sub-section and their applicability to traditional engineering majors are listed in *Table 5*. These courses, together with the math and science courses under the "General Core" section, correspond to the science and general engineering courses found in traditional undergraduate engineering majors, but are tailored to K-12 engineering and technology educational settings (here, "traditional undergraduate engineering majors" refer to mechanical, electrical/electronic, chemical/material, and civil engineering. Emerging fields of engineering such

as genetic and biochemical engineering need further investigation and are beyond the scope of this paper). Courses under these requirements include

- Engineering and technology courses that are featured across at least two traditional university undergraduate engineering majors, which would offer future K-12 engineering and technology teachers the opportunity to be trained in general topics of engineering and technology. For example, strength of materials and statics are two required courses for mechanical engineering and civil engineering students; electric circuitry and circuit analysis are two required courses for mechanical engineering and electrical engineering students.

- Engineering and technology curriculum development courses needed for development of K-12 engineering and technology curriculum using a variety of digital technology, such as ETES 5020/7020 - Communication Systems which covers a variety of digital technology for course content design and delivery; and ETES 2320 - Creative Activity for Engineering and Technology Teachers, which teaches students how to create entertaining learning activities in science, engineering and technology for elementary school pupils, through online and library research, creating of digital course materials, usage of engineering notebooks, and fabrication of physical models. In addition, due to the great potential of digital simulation technology in engineering analysis and design, the ETES 2320B - Digital Simulation for K-12 Engineering & Technology (3 hours) would be proposed, to prepare future generations of K-12 engineering and technology teachers for teaching digital simulation software such as:

    - FoilSim (http://www.grc.nasa.gov/WWW/K-12/FoilSim/index.html): The free software from NASA could be used in teaching and learning aerodynamic principles.

    - RocketModeler (http://www.grc.nasa.gov/WWW/K-12/rocket/rktsim.html): This NASA site provides engineering design simulation software for space science and related field, including rocket design for teaching scientific principles of weight, thrust, aerodynamic forces, lift and drag, and others.

    - West Point Bridge Designer: (http://bridgecontest.usma.edu/): This popular website, featured by The U. S. Military Academy at West Point, offers free bridge design simulation software (download site: http://bridgecontest.usma.edu/download.htm).

    - Yenka (http://www.yenka.com/en/Yenka_Gears/): From electronics PCB (Printed Circuit Board) simulation, to gears set (in full 3D mode) design, to statistics modeling, this website offers digital simulation software for a variety of engineering topics. A possible tool for infusing engineering analysis and design into K-12 curriculum.

2. <u>Engineering Analysis and Technology Options</u>: These courses could be organized into different options corresponding to both K-12 engineering and technology tracks (such as the State of Georgia Department of Education K-12 Engineering and Technology *Career Pathways*), and the undergraduate engineering majors (such those offered at UGA). Universities with K-12 engineering and technology teacher education programs could develop additional options according to the needs of local high school districts and of the undergraduate engineering programs offered at local universities. Students in the proposed K-12 Engineering and Technology Teacher Education program could choose one of the options. Under the proposed model, three Options have been developed. *Table 6* illustrate how these Options connect to both the State of Georgia Department of Education Engineering and Technology *Career Pathways* and the engineering majors at UGA, and list the courses to be included. In addition, they correspond to the careers of engineers and allied technologists with the greatest number of annual job openings projected by the U.S. Department of Labor for up to the year 2014 (refer to Appendix B for details). Due to differences in economic characteristics and corresponding collegiate engineering curricular program structure of different States and regions, additional options could be developed to satisfy local needs. Thus, the proposed model offers reasonable flexibility.

3. <u>Capstone Engineering Design</u>: There could be two courses in sequence; they could be based on the existing ETES 5110/7110 - Applications of Engineering in Technological Studies; however, the name of the course would be changed and the content would be modified in the direction of senior-year design courses in UGA undergraduate engineering programs (ENGR 4920. Engineering Design Project. 4 hours). Table 7 lists these courses.

Table 5. Foundation Engineering and Technology Courses

Foundation Engineering and Technology Course	Engineering Major Applicability
Engineering and Technology	
ETES 5010&5100 - Appropriate Engineering and Technology in Society (4 hrs)	All majors
ETES 5020A - Technical Design Graphics: 2D Drafting (3 hrs)	All majors
ETES 5060 - Energy Systems (3 hrs)	Mechanical, Civil, Electrical
ETES 5070 - Research and Experimentation in Technological Studies (3 hrs)	All majors
ETES 5090A - Principles of Technology I: Statics and Dynamics (4 hrs)	Mechanical, Civil
ETES 5090B - Principles of Technology II: Materials Strength and Selection (4 hrs)	Mechanical, Civil
ETES 5040 - Construction Systems (3hrs)	Civil, Environmental
ENGR 2110 - Engineering Decision Making (3 hrs)	All majors
Engineering and Technology Curriculum Development	
ETES 5020 - Communication Systems (3 hrs)	All majors
ETES 2320 - Creative Activities for Engineering and Technology Teachers (3 hrs)	All majors
Total hours: 33 hrs	

Table 6. Courses under Engineering Analysis and Technology Options

<table>
<tr><th colspan="2">Connection with External Program</th><th rowspan="2">Courses under the Engineering Analysis and Technology Options</th></tr>
<tr><th>Georgia DOE K-12 Engr. & Tech Career Pathways</th><th>Undergraduate Engineering Programs at UGA</th></tr>
<tr><td colspan="3">(1) Mechanical Design and Manufacturing Option (12 hrs)</td></tr>
<tr><td>Engineering Career Pathway;
Engineering Graphic and Design.</td><td>Mechanical System Engineering</td><td>• Fluid Mechanics (3 hrs)
• ETES 5090B - Principles of Technology II: Strength of Materials and Material Selection (3 hrs)
• Mechanism Design (3 hrs)</td></tr>
<tr><td colspan="3">(2) Manufacturing System Option (12 hrs)</td></tr>
<tr><td>Engineering Career Pathway;
Manufacturing Career Pathway</td><td>Mechanical System Engineering</td><td>• ETES 5030/7030 - Manufacturing Systems (3 hrs)
• Robotics and Automatic Systems (3 hrs)
• Production Enterprises (3 hrs)</td></tr>
<tr><td colspan="3">(3) Electrical and Electronics Option (12 hrs)</td></tr>
<tr><td>Engineering Career Pathway;
Electronics Career Pathway</td><td>Electrical Engineering
Computer Systems Engineering</td><td>• Foundations of Electronics (3 hrs)
• Advanced AC and DC Circuits (3 hrs)
• Digital Electronics (3 hrs)</td></tr>
</table>

Table 7. Capstone Engineering Design Courses

Capstone Engineering Design Courses	Engineering Major Applicability
ETES 5110B/7110B - Engineering Design I (3 hrs)	All majors
ETES 5110B/7110B - Engineering Design II (3 hrs)	All majors
Total hours: 6 hrs	

In the proposed model, changes would be made to include more engineering analysis and design courses in the K-12 Engineering and Technology Teacher Education program:

- Combination of courses with overlapping topics: The ETES 5010 (Technology and Society) and ETES 5100 (Appropriate Technological Development) could be combined into a single 4-hour course and could also incorporate the topic of engineering ethics. The new course can be designed as ETES 5010&5100 (Appropriate Engineering and Technology in Society). This combination would provide 2 hours of credit allocation for additional Foundation Engineering and Technology courses. Another option would be to keep both existing courses separate and thus to allow the total credit hours required for graduation to increase further.

- Name change and content modification of existing courses: The name of the course ETES 5110/7110. Applications of Engineering in Technological Studies could be changed to ETES 5110/7110 - K12 Engineering Design (two 3-hour courses). Mativo has changed the content of the ETES 5090 - Principles of Technology from physics to statics and dynamics; the name of the course would be changed to ETES 5090A - Principles of Technology I: Statics and Dynamics.

- Replacement: The EOCS 3010 - Introduction to Occupational Studies (3-hours) could be replaced by ENGR 1920 - Introduction to Engineering (2-hours). This change would not fundamentally alter the objective of the course being replaced; it would simply achieve the same objective with another course that is more relevant to the engineering and technology content of the proposed program.

Many new courses are proposed; and their descriptions are featured in Appendix B. A generic version for a possible NCETE model intended for any American public university is illustrated in *Table 8*. A specific version for the Technology Department of College of Engineering, Computer Science and Technology at California State University Los Angeles is available in Appendix F, including proposal for a Bachelor's degree program in K-12 Engineering and Technology Teacher Education, and descriptions for the proposed new courses.

A road map showing the sequence of engineering analysis and design content in the proposed B.S. degree program in K-12 Engineering and Technology Teacher Education is shown in *Figure 4*.

Table 8. The Proposed General Model of K-12 Engineering and Technology Teacher Education for the National Center for Engineering and Technology Education

GENERAL EDUCATION COURSES:

Subject to the particular requirements of the university offering K-12 Engineering and Technology Teacher Education program, but must include the following areas:

Area ? – Science, Mathematics and Technology – 23 Hours	
Math – 11 Hours	
Beginning Calculus (Integration and Differentiation)	4 hrs
Intermediate Calculus	4 hrs
Introduction to Linear Algebra	3 hrs
GENERAL EDUCATION COURSES (Continued)	
Physics – 8 Hours	
Introductory Physics (Mechanics, Waves, Thermodynamics) and Lab	4 hrs
Introductory Physics (Electricity and Magnetism, Optics, Modern Physics)	4 hrs
Chemistry – 4 Hours	
Beginning College Chemistry and Lab	4 hrs
Area ? - Course Related to Major – 10 Hours	
Socio-Cultural Diversity and Education	4 hrs
Learning and Teaching Methodology	3 hrs
Computer Applications for Teachers	3 hrs
Total General Core Hours	**68-69 hrs**

Table 8. (Continued)

MAJOR COURSES

College of Education Requirements

The K-12 Engineering and Technology Teacher Education Requirements - 15 Hours

Practicum in K-12 Engineering and Technology I	1 hr
Practicum in K-12 Engineering and Technology II	2 hrs
Introduction to Engineering	2 hrs
Curriculum Planning in K-12 Engineering and Technology Studies	3 hrs
Instructional Strategies in K-12 Engineering and Technology Studies	3 hrs
Students with Special Needs in Programs of Occupational Studies	3 hrs

Total Teacher Education Hours **14 hrs**

K-12 Engineering and Technology Education Area of Emphasis Requirements – 54 Hours

Foundation Engineering and Technology Courses – 36 Hours

Engineering and Technology – 30 Hours

Appropriate Engineering & Technology in Society	4 hrs
Technical Design Graphics: 2D Drafting	3 hrs
Energy Systems	3 hrs
Research and Experimentation in Technological Studies	3 hrs
High School Statics and Dynamics	4 hrs
High School Materials Strength & Selection	4 hrs
Construction Systems	3 hrs
Engineering Decision Making (Engineering Economics)	3 hrs
Laboratory Planning, Management, and Safety	3 hrs

Engineering and Technology Curriculum Development – 6 Hours

Digital Communication Systems	3 hrs
Creative Activities for Engineering and Technology Teachers	3 hrs
Digital Simulation for K-12 Engineering & Technology	3 hrs

Engineering Analysis and Technology Options: - 9-12 Hours

Any option with 3 courses (3 semester hours each) could be developed according to needs. The following is an example:

Mechanical Design Option - 12 Hours

Technical Design Graphics: 3D Solid Modeling and Design	3 hrs
Fluid Mechanics and Aerodynamics	3 hrs
Heat Transfer & Thermodynamics	3 hrs
Mechanism Design and Selection	3 hrs

Table 8. (Continued)

MAJOR COURSES (Continued)

Capstone Engineering Design Courses – 6 Hours

K-12 Engineering Design I	3 hrs
K-12 Engineering Design II	3 hrs

K-12 Engineering and Technology Education Area of Emphasis Subtotal 57 hrs

TOTAL SEMESTER HOURS REQUIRED FOR GRADUATION 133-134 HOURS

Note:
Under the proposed program, the total number of science, engineering analysis and design courses is 22; and the total semester hours is 73 (57% of the total semester hours required for graduation):

Total General Core Hours (Except Math and Science)		**42-43 Hours**
Area D – Science, Mathematics and Technology	**7 Course**	**26 Hours**
K-12 Engineering and Technology Education Area of Emphasis Requirements	**17 Courses**	**4 Hours**
Total Credit Hours for Graduation:		**122-123 Hours**

Under the proposed program, the students will acquire adequate ability to conduct and teach analytic analysis-based engineering design to K-12 engineering and technology students. Thus, engineering design is thoroughly incorporated into the K-12 Engineering and Technology Teacher Education program.

Incorporation of the conclusions from the dissertation of Dr. Phillip Cameron Smith Jr. into the proposed model

Smith and Wicklein (2006, pp. 68-72) tabulated and statistically analyzed responses by survey participants to the following Research Questions and listed items that could be placed under the category of engineering analysis and design; all of these items have been incorporated into the courses listed under the proposed model (Table 4 and Table 8):

1. "What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?" (Items No. 1 - 39h)

2. "What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?" (Items No. 40 - 58g)

3. "What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?" (Items No. 59 - 79e)

4. "What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?" (Items 80 – 93d)

Table 9 below illustrates how Dr. Smith and Dr. Wicklein's items have been incorporated into the proposed courses. Notice that only the items having received mean scores of more than 3.25 (out of 5.0 in the Likert Scale) as important items from participants' responses have been selected for incorporation.

Table 9. Incorporation of Dr. Smith and Dr. Wicklein's items into the Proposed Courses

Science, Technology, Engineering and Mathematics (STEM) Courses		
New UGA Courses under the Proposed Model	**Item Incorporated**	
	No.	**Name and Mean Score**
Math 3000 - Introduction to Linear Algebra (3 hrs)	40	Basic Algebra (5.54)
	41	Advanced Algebra (4.62)
	42	Linear Algebra (3.62)
Math 1113 - Precalculus (3 hrs)	43	Geometry (5.46)
	44	Trigonometry (5.00)
	45	Pre-Calculus (4.62)
Math 2260 - Calculus II for Science and Engineering (integration) (4 hrs)	47	Calculus - Integration (3.25)
Math 2250 - Calculus I for Science and Engineering (Differentiation) (4 hrs)	48	Calculus - Differentiation (3.17)
	51	Approximation (4.54)
Physics 1111-1111L - Introductory Physics (Mechanics, Waves, Thermodynamics) (4 hrs)	58b	Conservation of momentum (4.08)
	58c	Projectile motion (3.25)
	62	Conservation of mass, energy and momentum (4.67)
	65	Newton's laws: forces, reactions, velocity & acceleration (5.42)
ETES 5090A - Principles of Technology I: Statics and Dynamics (4 hrs)	58d	Structural equilibrium (4.50)
	58e	Basic stresses (4.42)
	63	Dynamic systems (4.08)
	66	Summation of forces/force equilibrium (5.00)
	73	Statics (4.50)
ETES 5090D - Principles of Technology IV: Heat Transfer and Thermodynamics (3 hrs)	71	Heat and mass balances (3.58)
	72	Heat transfer (3.58)
	75	Thermodynamics (3.33)
	79b	Thermal expansion/contraction (4.00)

Table 9. Continued.

New UGA Courses under the Proposed Model	Item Incorporated	
	No.	**Name and Mean Score**
• Chemistry 1211-1211L - Freshman Chemistry I and Lab (4 hrs) • ETES 5090B - Principles of Technology II: Materials Strength & Selection (4 hrs)	59	Chemical properties of materials (3.83)
	74	Strength of materials (4.42)
ETES 5090E - Mechanism Design & Selection (3 hrs)	58a	Algebraic equations for determining gear ratios (2.83)
	64	Introductory mechanics (4.45)
	90	Basic mechanical mechanisms (4.17)
ETES 5090C - Principles of Technology III: Fluid Mechanics & Aerodynamics (3 hrs)	70	Fluid flow (3.42)
• ETES 5020A - Technical Design Graphics: 2D Drafting • ETES 5020B - Technical Design Graphics: 3D Solid Modeling and Design (3 hrs), and • ETES 2320B - Digital Simulation for K-12 Engineering & Technology (3 hrs)	57	Modeling/simulation/numerical analysis software (3.64)
	80	Computer aided design software (4.00)
• Physics 1112-1112L - Introductory Physics (Electricity and Magnetism, Optics, Modern Physics) (4 hrs) • ETES 5090H – Electronics Circuitry & Component Selection (3 hrs), • ETES 5090I - Advanced AC and DC Circuits (3 hrs), and • ETES 5090J - Digital Electronics (3 hrs)	68	Circuit analysis and electrical power (3.75)
• ETES 5010&5100 - Appropriate Engineering & Tech. in Society (4 hrs)	79e	Principles related to environmental consciousness (4.42)
ETES 5060 - Energy Systems (3 hrs)	67	Types of energy (5.25)
• EDIT 2000 - Computing for Teachers (3 hrs) • ETES 2320 - Creative Activities for Engineering Technology Teachers (3 hrs) • ETES 5020 - Communication Systems (3 hrs)	55	Computer Programming (3.92)
	56	Spreadsheets (5.23)
	81	Computer searching (4.67)
	84	Presentation software (5.00)
	88	Historical perspective (4.42)

Table 9. Continued.

Engineering and Technology Design Courses

New UGA Course under the Proposed Model	• ENGR 2110 - Engineering Decision Making (3 hrs) • ETES 5070 - Research and Experimentation in Technological Studies (3 hrs) • ETES 5110A/7110A - Engineering Design I (3 hrs) • ETES 5110B/7110B - Engineering Design II (3 hrs)

Item Incorporated

No.	Name and Mean Score	No.	Name and Mean Score
1	Understand problem identification, formulation, development of requirements lists (5.38)	34	Understanding product life cycles/life cycle analysis (4.38)
2	Understand functional structures (4.25)	35.	Critical thinking (5.23)
3	Understanding of customer needs (5.00)	36	Experience (3.62)
4	Project planning and scheduling (4.54)	37	Logic and logical thinking (4.85)
5	Teamwork (5.31)	38	Systems thinking (5.69)
6	Decision making methodologies (4.58)	39a	Costing, profit, and basic economic analysis (3.50)
7	Written communication (5.08)	39b	Understanding the context of the technological problem and possible external influences (4.75)
8	Oral communication (5.54)	39c.	Product architecture and modularity/interfaces (3.67)
9	Graphical/pictorial communication (5.54)	39d	Design principles to assist in generating innovative concepts (4.67)
10	Negotiation (4.42)	39e	Design by analogy (4.17)
11	Meeting skills (4.62)	39f	Understanding basic business motivations for engineering design, such as marketing or consumer research (4.00)
12	Personal ethics (5.15)	39g	Understanding basic manufacturing processes (4.25)
13	Multicultural/diversity awareness (4.08)		39h House of Quality method (3.25)
14	Ability to break down complex problems in manageable pieces (5.17)	46	Statistics (4.25)
15	Ability to handle open-ended/ill defined problems (5.77)	52	Ability to handle open-ended/ill-defined problems (5.54)
16	Ability to integrate multiple domains of knowledge (5.08)	53	Multiple solutions to a single problem (5.69)

Table 9. Continued.

No.	Name and Mean Score	No.	Name and Mean Score
17	Acceptance of multiple solutions to a single problem (5.77)	54	Optimization (2.85)
18	Brainstorming and innovative concept generation (5.15)	58f	Using geometry and trigonometry to change the scale of a component (3.92)
19	Conceptual design (5.23)	58g	Formulas capable of expressing the performance of a system (4.25)
20	Design for robustness/failure mode analysis (3.54)	76	Decision analysis (3.67)
21	Engineering heuristics for analysis-based design (3.45)	79a	Project management (4.25)
22	Experimental design, data collection, and interpretation of results (4.54)	79c	Question asking - inquiry (4.58)
23	Functional product modeling (4.46)	79d	Leadership principles (3.58)
24	Human factors and safety in design (4.62)	85	Ability to abstract (5.17)
25	Identification of good/bad design (4.62)	86	Ability to synthesize (5.75)
26	Identification of underlying scientific principles (5.08)	87	Analogical reasoning (5.17)
27	Product optimization (3.08)	89	Analysis-based design (4.17)
28	Product testing/functional analysis (4.38)	92	Product Dissection (4.58)
29	Prototyping/fabrication skills (4.77)	93a	Reverse engineering (4.17)
30	Recognition that the solution method depends on the type of problem at hand (4.62)	93b	Finishing job to the last detail (3.67)
31	Research/library skills (4.85)	93c	Recognizing team roles and personality types (4.58)
32	Simplicity and clarity of use and function (4.77)	93d	Engineering intuition (3.45)
33	Synthesis of simple parts into more complex system (4.69)		

Engineering Analysis & Design Sequence	Courses in the Proposed K-12 Engineering and Technology Teacher Education Program
Math and Science Foundation → ↓ **“Creative Conceptual Design” Component** (Fostering broad exposure to science and technology, and ability of creative imagination) ↓	**Math** • Beginning Calculus (Integration and Differentiation • Intermediate Calculus • Introduction to Linear Algebra **Physics** • Introductory Physics (Mechanics, Waves, Thermodynamics and Lab • Introductory Physics (Electricity and Magnetism, Optics, Modern Physics) **Chemistry** • Beginning College Chemistry and Lab **Creative Conceptual Design** • Creative Activities for Technology Teachers
Engineering Foundation (Analytic) → **“Microscopic Design”** ↓ **“Analytic Reduction” Component** (Well-structured and simple engineering design problem) ↓	**Engineering and Technology** • Appropriate Engineering & Technology in Society • Technical Design Graphics: 2D Drafting • Energy Systems • Research and Experimentation in Technological Studies • Statics and Dynamics • Materials Strength & Selection • Construction Systems • Engineering Decision Making (Engineering Economics) • Laboratory Planning, Management, and Safety
Engineering Major (Analytic) → **“Microscopic Design”** ↓ **“Systems Thinking” Component** (Ill-structured and complex engineering design problem) ↓	**Engineering Analysis & Technology Options (choose one):** **1. Mechanical Design and Manufacturing Option** • Technical Design Graphics: 3D Solid Modeling & Design • Fluid Mechanics • Mechanism Design and Selection **2. Manufacturing System Option** • Manufacturing Systems • Robotics and Automatic Systems • Production Enterprises **3. Electrical and Electronics Option** • Foundations of Electronics • Advanced AC and DC Circuits • Digital Electronics
Senior Design → **“Macroscopic design”**	**Capstone Engineering Design Courses** • K-12 Engineering Design I • K-12 Engineering Design II

Figure 4. Road map showing the sequence of engineering analysis and design content in the proposed K-12 Engineering and Technology Teacher Education.

Part Three

The Overall Structure of the Proposed Model for Infusing Engineering Design into K-12 Engineering and Technology Teacher Education Curriculum: A The Four-Stage Model

The ultimate goal of the proposed model for infusing engineering design into K-12 Engineering and Technology Teacher Education program is to serve future K-12 student needs with qualified teachers. The needs of future K-12 students to learn engineering design shall be discussed now.

Previous studies conducted in Sweden indicated that "students as young as 5 to 7 years old" can engage in simple creative design activities (Druin & Fast, 2002, pp. 192-194). Although kindergarten and elementary school pupils barely start exposure to science and cannot be expected to possess a lot of analytic design abilities, they nevertheless can engage in the process of conceptual design ideation, if proper guidance is provided.

Jonassen, Strobel and Lee (2006, pp. 139-141) analyzed substantive differences between "classroom problems" and "workplaces problems." The classroom problems are "story (word) problem" with parameters "specified in the problem statement;" they are "well-structured" and can be solved by "applying preferred solution methods." The workplace problems are complex and ill-structured, do not have standard solutions, but "have vaguely defined or unclear goals and unstated constraints." The above statement being true, it is nevertheless important for us to understand that the ability to solve well-structured "story (word) problem" is actually laying the foundation for fostering the ability to solve ill-structured "workplace problems."

With such understanding, the proposed model for infusing engineering design into K-12 Engineering and Technology Teacher Education program could include two major curricular structures: (1) the Regular Curriculum; and (2) extracurricular enrichment.

Linearly incremental progression of engineering design process in regular curriculum

The Regular Curriculum is designed for all K-12 students regardless of academic achievement; it divide the engineering design process into four stages, each corresponding to the infusion of engineering design into a period of K-12 education (namely, kindergarten to elementary, middle an high schools); and by implementing engineering design process stage-by-stage, from simple to complex, as a linearly incremental progression model of infusing engineering design in K-12, it has the potential of raising the general engineering and technology literacy of all American K-12 students, and make a contribution to narrowing the K-12 academic achievement gaps as well as disparity in representation in engineering education and profession among students of different races, ethnicity and gender. Thus, it reflects John Dewey's ideas of democracy and equality in education (see *Figure 4*). The four stages are:

1. <u>"Creative Conceptual Design" Stage</u>: This component of the proposed model is intended to foster broad exposure to science and technology, and ability of creative imagination, through "educational entertainment" style science and technology learning projects, using time-tested mechanisms of creative ideation such as brainstorming sessions. The focus of this component is conceptual design ability, or the ability to imagine and to envision. The ETES 2320 (Creative Activities for Technology Teachers) offers this training, which could be used to teach engineering design to kindergarten and elementary school pupils.

    2. <u>"Engineering Experiment" Stage with "Technology Education Design Approach" for well-structured experimental design problems</u>: Students will learn how to analyze relevant data, make reasonable hypothesis, propose several design solutions, and conduct actual physical fabrication and testing to select the most suitable design solution through comparison. This is basically a "trial-and-error" or "hypothesis-and-verification" approach. For example: students could design, fabricate and test a compound material by first collecting and analyzing data on materials to be mixed, design several possible mixtures based on reasonable hypothesis, then fabricate and test the mixtures to determine which mixture yields the strongest compound material.

    3. <u>"Analytic Reduction" Stage of "Microscopic Design" for well-structured problems</u>: Throughout the engineering foundation and analysis courses, under the sub-sections of "Engineering and Technology" and "Engineering Analysis and Technology Options," in the section of "K-12 Engineering and Technology Education Area of Emphasis," well-structured and simple design problems could be explored. The focus of this component is to apply engineering analytic and predictive principles and skills from one to several fields of study to solve simple engineering design problems, although the "Creative Conceptual Design" Component will still be employed. According to Jonassen (1997, pp. 65-66), the <u>model of solution for well-structured problems</u> is "based on information processing theories of learning;" the <u>instructional design</u> uses "information processing theories that conceive of learning outcomes as generalizable skills that can be applied to any content domain." This component of engineering and technology teacher education corresponds to the need to infuse engineering design into middle school engineering and technology curriculum. In terms of coursework assignments, students could be offered the following choices:

        - <u>Research Project</u>: Students could conduct research on how particular principles of science and engineering are used in practical engineering design, through online and library research, and onsite visits; write research reports and develop relevant instructional materials, such as lesson plans, development of design problems, and others, to be used as supplements for adopted textbooks; or

- Semester Final Design Project: Students could design simple but fully functional products or systems with a few components, using principles of science and engineering learned during the courses, and following the above-mentioned Engineering and Technology Design Process (refer to *Figure 3*), with comprehensive sets of portfolio items including engineering notebooks, reports on research, analysis, computations, prediction, testing, outcome, as well as 3D digital modeling and 2D drafting, simulation printouts, PowerPoint files, physical prototypes and pictures, and other artifacts.

4. "Systems Thinking" Stage of "Macroscopic design" for ill-structured problems: In the Capstone Engineering Design courses, students could integrate their engineering analytic and predictive skills, and use principles of Engineering and Technology Design Processes (refer to *Figure 3*), to design complex and functional products or systems, with several sub-assemblies and many components, and come up with comprehensive sets of portfolio items. The focus of this component is to apply engineering analytic and predictive principles and skills from many fields of study, plus knowledge about social, economical, ecological and other issues, to solve complicated and complex engineering design problems; the "Creative Conceptual Design" Component and "Systems Thinking" abilities will be keys to success. According to Jonassen (1997, pp. 65-66), the model of solution for ill-structured problems relies on "an emerging theory of ill-structured problem solving and on constructivist and situated cognition approaches to learning;" and in its instructional design, problem solving is "domain- and context-dependent and constrained by context." This component of engineering and technology teacher education corresponds to the need to infuse engineering design into high school engineering and technology curriculum.

Pedagogy: The last stage of the proposed model ("Systems Thinking" stage) could be the ultimate result expected by the efforts at infusing engineering design into the K-12 Engineering and Technology Teacher Education program. Future teachers could not only learn how to solve workplace engineering design problems, but also formulate appropriate pedagogy for transferring related knowledge and skills to future K-12 students. This could be accomplished in: (1) Capstone Engineering Design courses; and (2) K-12 Engineering and Technology Teacher Education Requirements courses. In my understanding, the key to successful pedagogy in this area is teacher-learner relationships. In terms of pedagogy, Davis and Sumara (pp. 5-6) listed some areas of "complex dynamics" to be considered, such as "teacher-learner relationships, classroom dynamics, school organizations, community involvement in education, bodies of knowledge, and culture;" and they explored the application of complexity thinking in teaching and learning process, with the ideas that learning is "due to" the learner's own complex biological-and-experiential structure, not an external stimulus, and "teaching cannot cause learning;" and that, instead of being "isolated and insulated individual," "learners can include social and classroom groupings" (pp. 12-14). These ideas could help us break off from the constraints of the teacher-centered, behaviorist "cause-effect logic" and "stimulus-response" model, and develop a student-centered new paradigm based on the understanding of the students' learning process. With regard to K-12 engineering and technology education, we could focus our pedagogy on students' learning experience, and adapt our pedagogy to better suit students' needs, by developing our pedagogy from the perspectives of the learners, instead of from the perspectives of the instructors. It is also possible for us to go beyond the paradigm of competition among individual students to paradigm of cooperation among them, through team works, mutual tutoring and other means.

Benefit to innovation: "Systems Thinking," the underlying philosophic framework for the last component of the proposed model is beneficial for promoting innovative solutions. Banathy et al (n.d.) explored the merits of deigning brand new systems in "times of accelerating and dynamic changes" or "when we have evidence that changes within the system would not suffice," instead of attempting to improve the existing systems by "adjusting or modifying the old design," (pp. 50-51). Furthermore, Banathy et al (n.d.) quoted the three properties of "idealized design" from Ackoff's model (1981): (1) technologically feasible, (2) operationally viable, and (3) capable of rapid learning and development (p. 51). As we all know, the United States is currently facing the crises of chronicle shortage in science and engineering graduates; we need to explore ways to improve the current educational system (especially the current practices in K-12 engineering and technology education) as well as to initiate innovative ones (such as inculcating analytic and predictive engineering design skills in high school students by infusing some portions of lower-division engineering courses, which are based on pre-calculus mathematics, into current high school technology curriculum).

Detailed description of sample units from courses in the proposed program that include engineering design is available in Appendix A-1 ("Creative Conceptual Design" Stage), A-2 ("Technology Education Design" Stage), A-3 ("Analytic Reduction" Stage, using "Combined Engineering and Technology Design Process"), and A-4 ("Systems Thinking" Stage, using "Combined Engineering and Technology Design Process").

Recursive iteration of engineering design process in extracurricular activities

In addition to infusion engineering design process as a linearly incremental progression in regular curriculum, which is designed for average K-12 students, academically challenging extracurricular enrichment engineering design activities would be made available to K-12 students with strong interests in pursuing science, engineering and technology and completion of some prerequisite courses. In these engineering design activities, to be organized as extra-credit semester design projects, after-school activities, or summer camps, challenging engineering design with open-ended, and ill-structured interdisciplinary problems would be explored by K-12 students even at the elementary level, using available resources from Project Lead The Way, and others (such as Mativo's

Animatronics projects to be explained later in this paper). Such open-ended and interdisciplinary projects and activities could also serve as opportunities to review and to apply science, engineering and technology principles learned from different STEM courses, and thus, increasing K-12 students' ability at synthesizing knowledge content to solve real world problems. This reflects the ideas of academic upward mobility and efficiency.

Part Four

The Ultimate Expected Outcome of the Proposed Model: A Focus on Future K-12 Students

A streamlined engineering and technology education across K-12 and collegiate levels

<u>Training qualified teachers for the time being</u>: The immediate purpose of the proposed model of infusing engineering design into K-12 Engineering and Technology Teacher Education program is to prepare qualified teachers for K-12 engineering and technology *Career Pathways*. Future graduates from K-12 Engineering and Technology Teacher Education program would be equipped with: (1) solid mastery of general engineering knowledge content, plus specialized engineering problem solving skills (in mechanical, electrical, civil, and manufacturing fields), both up to early calculus (integration and differentiation in up to three-dimensions) and linear algebra levels, which are sufficient for practical engineering design; (2) adequate understanding of the K-12 education process and the ability to confidently teach, manage and design K-12 engineering and technology programs; (3) the ability to conduct research related to practical design, in specialized fields of engineering and technology, for industry and community; this ability would allow graduates to teach K-12 students while keeping in touch with and serving societal needs; (4) the ability to design simple to complex, fully-functional products and systems (such as kitchen appliances, power tools, solar energy systems for household and community use, etc.). In fact, the proposed model would be an integration of state of art modern science and technology, practical engineering (or "light version" of a typical engineering program), and K-12 teacher training.

<u>Educating new generations of inventors for the near future</u>: The ultimate purpose is to educate new generations of innovative engineers or professionals in other fields. This ultimate purpose could be accomplished by launching K-12 students early into engineering and technology orbit, so that they could foster analytic and innovative capacities early in their life. Modern engineering education is more complicated than ever before, due to explosion of new knowledge and technologies, especially those related to digital modeling and simulation. In addition, traditional engineering education has been somehow challenging to students due to heavy requirements on calculus-base mathematics, physics and engineering course works. Therefore, launching students early onto the engineering orbit would make sense.

Edu-tainment →
Kindergarten through elementary school:

Curricular Focus and Expectation:

A. Playing with technology: Introduction to engineering and technology, and injection of interests in science, engineering and technology careers;

B. Building a solid foundation in basic arithmetic: By integrating some simple engineering topics such as scaling in drafting, volume and density, surface area and pressure, etc.

C. inculcation of creativity with conceptual design projects to be further worked into analytic design at middle school, high school and university level.

Infusion of Engineering Design: Conceptual and light analytic; simple and well-defined problems

Curricular Model:

City Technology, Focusing on everyday objects as teachable subjects, such as shopping bags (instead of bridge) for learning the topic of structure, a pair of scissors, a nail clipper, and a staple remover (instead of robots) for studying the basic elements of levers.

Transition to Next Step:

From inculcation of interests in science, engineering and technology to introduction to the fields of engineering.
→

→

Initiation →
Middle school:

Curricular Focus and Expectation:

A. Exploring technology: Study of the basics of technology, including both traditional production, fabrication and construction methods, and modern computer-aided prototyping and manufacturing process;

B. Consolidate mathematics foundation: By integrating mathematics with physics and chemistry, and by injecting additional engineering topics such as simple mechanical devices (fasteners, gears, linkages, etc.) into mathematics course;

Infusion of Engineering Design: Conceptual and moderately analytic; simple and well-structured problems

Curricular Model:

Dr. Wicklein's model, or **High School That Works**, with Engineering Concepts course (including the topics of ergonomics and appropriate technology), and Introduction to Engineering Graphics (CAD) course that covers basic product and mechanism design.

Transition to Next Step:

From conceptual to analytic and predictive abilities in engineering design; and from creative ideas to creative design.
→

→

Extensive Study →
High school:

Curricular Focus and Expectation:

A. Exploring engineering: The analytic foundation of engineering (pre-calculus portions of lower-division undergraduate engineering program, such as statics, fluid, mechanics of materials, mechanism, selection of materials or material science), in physics and chemistry or as stand-alone courses;

B. Completing the pre-engineering mathematics: All pre-calculus courses plus beginning calculus (integrals and differentiation);

C. Engineering Design Certificate Program: Completing 1-2 engineering design "capstone" courses, with a professional portfolio of product/simple mechanism design (ready for production). Expectation for graduates: (1). Qualified to work in industry as beginning product designers or engineer's assistants, with some additional courses if needed, or (2). Well prepared for a major in engineering, technology or science at college level.

Infusion of Engineering Design: Conceptual and reasonably analytic; simple and well-structured problems, to moderately complex and ill-structured problems

Curricular Model:

Project Lead The Way, or **Engineering by Design**, with some localized modification.

Transition to Next Step:

From basic to increased analytic and predictive abilities in design (consumer products to robotics, etc.).→

→

College or university:

Curricular Streamlining:

A. Articulation: For the pre-calculus portions of lower-division undergraduate engineering program , cross-institutional articulation between high school and university engineering programs, with FE-style examination designed for high school students graduating from Engineering Design Certificate Program (partial credits in the university lower-division engineering courses; students will continue to take these courses, but with the inclusion of a creative design component);

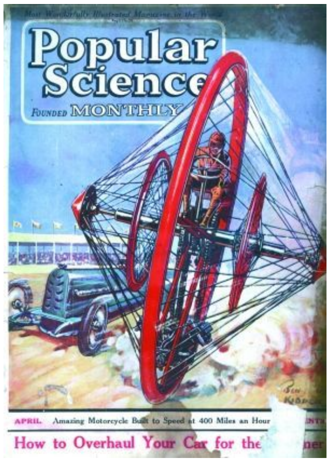
B. Resource sharing: High schools and universities can share engineering experiment and computer-aided prototyping facilities, as well as library resources;

C. Internet-based joint curriculum: Some appropriate engineering course content can be delivered through Internet to both high school and high school and university students.

D. Tutorial service: College engineering students (sophomores and up) can serve as tutors for high school engineering programs (an opportunity to consolidate knowledge base and gain people skills).

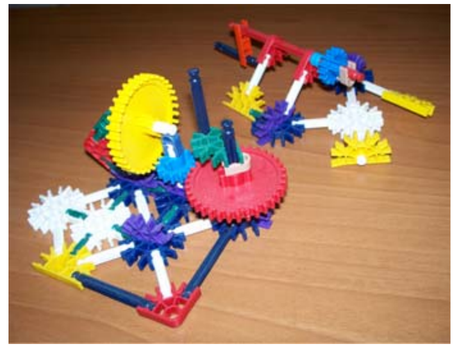
Infusion of Engineering Design:
Lower-division: Conceptual and reasonably analytic; simple and well-structured problems, to moderately complex and ill-structured problems.
Upper-division: Analytic; complex and ill-structured problems.

Figure 5. Road Map for an Integrated Engineering and Technology Curriculum (K-12 to College) for Mechanical Engineering Career Pathway



Single-wheel motorcycle

Flying tank



Toy gears

Figure 6. Encouraging K-5 pupils science fiction style creative imagination and teaching simple engineering design with gear assembly toys (Source: http://www.chinapressusa.com/2009-01/02/content_180084.htm)

By carefully and sequentially incorporating engineering analysis and design into K-12 curriculum, we could help K-12 students to increase their knowledge and skills in engineering and technology step-by-step, with smooth and streamlined transition across different levels of their academic journey, as illustrated in *Figure 5*.

Infusion of engineering design throughout the K-12 education

As shown in *Figure 5*, the infusion of engineering design throughout K-12 education could be divided into three stages, each transiting smoothly into the next; and this transition could be considered as analogous to the launch of a spacecraft into the outer space, where the birth of new generations of creative engineers are analogous to spacecrafts starting new journeys of discovery, as illustrated in *Figure 7*:

1. Kindergarten and elementary school years: During this stage, students would be introduced to engineering and technology, through either a. stand-alone technology courses with entertaining educational projects that incorporate basic principles of science, engineering and technology (similar to projects taught in ETES 2320 - Creative Activities for Technology Teachers at the University of Georgia); or b. incorporation of appropriate subjects of engineering design into regular arithmetic, science and English courses. Infusion of engineering design would be mostly conceptual and lightly analytic, using simple and well-structured problems. During this period, students should be given an opportunity to: (1) have a broad exposure to diverse aspects of science, engineering and technology (the “breadth”); and (2) foster ability of creative imagination, in a fashion similar to “science fiction” (the “wild”); and (3) foster a systemic and holistic view of technologies as interactive and interconnected, through either former courses or extracurricular enrichment activities. Conceptual brainstorming could start during these years, supplemented with very simple analytic skills. During this stage, pupils would master similar knowledge content that are traditionally required of

college engineering and technology students in these courses (1) Introduction to Science, Engineering and Technology; (2) Engineering Ethics; and (3) Appropriate Engineering and Technology. In addition, they would build a broad knowledge base on diverse branches of modern and traditional engineering and technology, plus the initial ability to conceptually imagine and to freely create (through brainstorming sessions). This stage corresponds to the launching ground in the spacecraft analogy.

2. Middle school years: During this stage, students would consolidate their mathematics and science foundations; and explore the basics of traditional and modern technology. Infusion of engineering design would be both conceptual and moderately analytic, using simple and well-structured problems. During this stage, students would master the fundamentals of modern technology which is associated with engineering design, such as CAD and 3D modeling, traditional and CNC manufacturing process, and others. This would prepare them for either engineering and/or technology majors at university level. In addition, they would master the basics of science and engineering experiments, using traditional Technology Design Approach. This stage corresponds to the launching pad in the spacecraft analogy.

3. High school years: During this stage, students would be introduced to pre-calculus based engineering foundation courses, similar to those listed under the previously discussed *Career Pathways* established by the State of Georgia Department of Education, and in the relevant sections of Table 4 and Table 8 (such as statics, fluid, materials strength and selection, mechanism design and selection). Infusion of engineering design could include: (1) conceptual and reasonably analytic design projects solving simple and well-structured problems in relevant engineering analysis courses; and (2) conceptual and reasonably analytic design projects solving moderately complex and ill-structured problems in “capstone” engineering design courses. During this stage, students would master the pre-calculus portions of many engineering subjects, which up to this point have been offered in the lower-division courses of undergraduate engineering programs. In the future, special examinations modeled after FE (Fundamentals of Engineering) could be designed to test the abilities of high school graduates to solve pre-calculus level engineering problems; and for those who pass the examinations, special accommodations could be granted such that, they would still be enrolled in regular lower-division undergraduate engineering courses to continue studying relevant topics beyond the pre-calculus portions they have learned at high schools, but be exempted from the home works and quizzes related to the pre-calculus portion of course content, devoting their time instead to engineering design and research projects. This stage corresponds to the initial stage rocket propulsion in the spacecraft analogy.

4. Transition to university engineering majors: As illustrated in the rightmost column in *Figure 5*, many streamlined transitional mechanisms across high-school and university levels could be developed together with the codification of K-12 engineering curriculum, to make the whole process of engineering and technology education more cost-effective and fruitful. The stage of university level engineering and technology

education corresponds to the second stage rocket propulsion in the spacecraft analogy, after which the new generations of innovative engineers could start their creative careers.

5. <u>Post-university technological upgrades</u>: The advance of digital technology, such as computer-aided-design/drafting (CADD), computer-aided-manufacturing (CAM), and computer simulation, will increasingly offer creative engineers possibilities to save time spent on tedious mathematical computations, to concentrate on creative design strategy, and thus, to increase efficiency in engineering design process. In many places in the United States, such as in Los Angeles and Orange Counties, California, two-year community colleges offer extensive programs to teach engineering-related digital technology skills. The application of digital design and simulation technologies in engineering analysis and design processes could be analogous to a space station that provides maintenance service to spacecrafts (*Figures 7 and 8*).

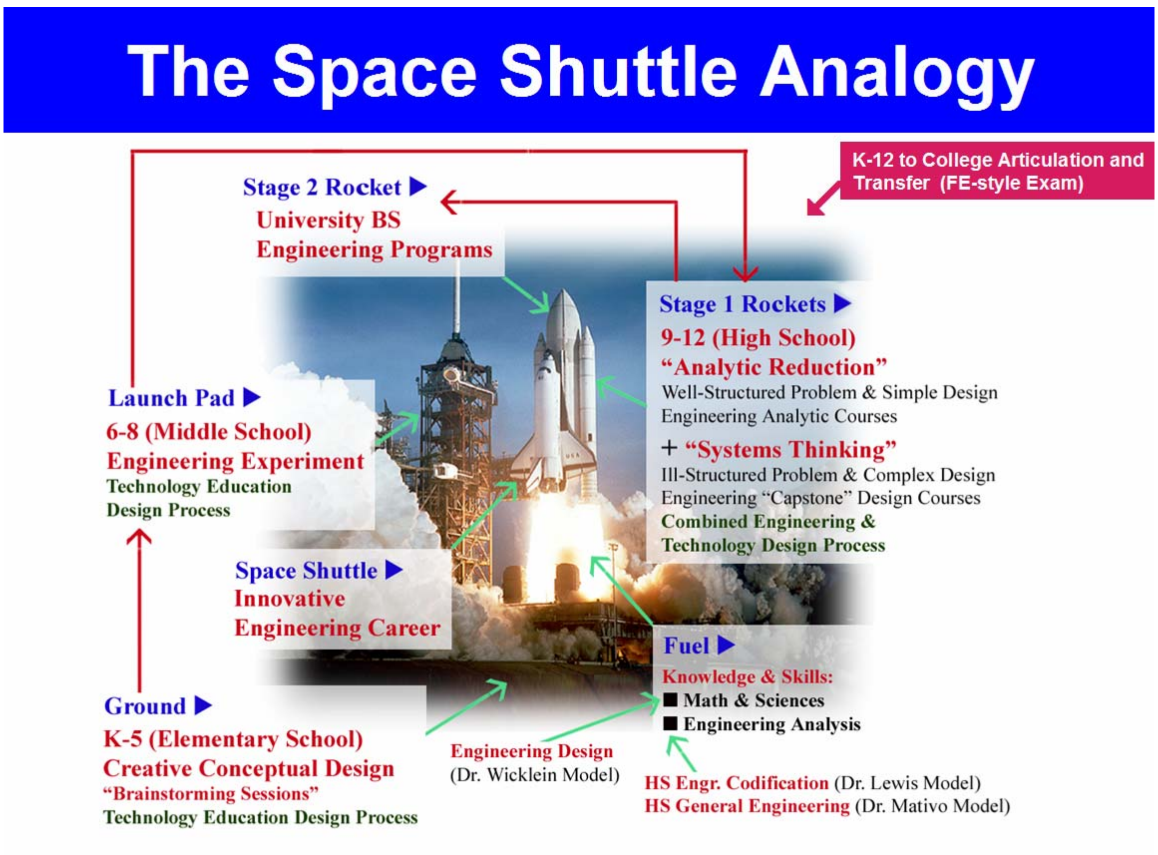


Figure 7. "Space shuttle launch" analogy for the sequence of infusion of engineering design across K-12 and collegiate levels.

Figure 8. "Space station" analogy for the post-baccalaureate upgrading of innovative engineering design capabilities, through graduate schools, or continuing training of digital simulation, CAD, CAM and other engineering design related technologies.

Pilot pedagogic experiments could be considered to test the above discussed model, which could lead to:

1. <u>Infusion of appropriate engineering content knowledge into K-12 math and science curriculum</u>: This methodology, to be further discussed in the next section, is based on Wicklein' idea of design as the integrating factor linking engineering and science through high school technology program (2006, p. 25);

2. <u>Stand-alone K-12 engineering analysis and design courses</u>: Wicklein and Thompson (2008) indicated that "a high school technology education curriculum centered on engineering would include a series of focused courses and instructional activities that lead a student through the engineering design process." Codification of appropriate engineering topics for high school students, based on Lewis' idea of a "codified body of knowledge that can be ordered and articulated across the grades" could be used to systematize the state of the art in engineering in a way that is translatable in schools (2007, p. 846-848); this idea also answers Mativo's call for inclusion of "general engineering" topics (personal conversation, December 17, 2008).

Vital issues affecting contemporary engineering design and innovation

Escaping our own Ivory Tower: Many scholars indicated that there is a need for scientific and engineering communities to break off from their own ivory towers and to embrace other vital aspects of human endeavors, with a deep understanding of the "inter-disciplinary" and "complex" attributes of modern engineering design. Weaver (1948, pp. 4-6) believed that the future of the world "requires science to make a third great advance," to "learn to deal with these problems of organized complexity." He cited as an example the wartime development of new types of electronic computing devices which eventually gave birth to personal computers; and challenged the readers to think about a wide range of problems in the biological, medical, psychological, economic, and political sciences, posing interesting questions such as "with a given total of national resources that can be brought to bear, […] what sacrifices of present selfish interest will most effectively contribute to a stable, decent and peaceful world?" He then indicated that these problems are beyond the statistical techniques or even the whole of scientific methods, but involve other "rich and essential parts of human life," such as code of morals, basis for esthetics, man's love of beauty and truth, sense of value, or convictions of faith, "which are immaterial and non-quantitative in character, and which cannot be seen under the microscope, weighed with the balance, nor caught by the most sensitive microphone."

Trashing the so-called "valueless education:" As a great advice for the appropriate application of scientific knowledge for human welfare, Weaver pointed out that "our morals must catch up with our machinery" (1948, p. 7). This challenged me to wonder that, due to serious problems that challenge our democratic society (such as inappropriate use of technology causing pollution and other human disasters), we need to reconsider the wisdom of "valueless education," and strengthen ethical values, such as concern for the collective well-being of the society, and environmental protection, as important parts of K-12 engineering and technology education.

Embracing global sustainability: Wicklein (2008) explained *Appropriate Technology* (AT) as "a concept which embodies providing for human needs with the least impact on the Earth's finite resources," and concluded that "advanced technology is often inappropriate for the needs that it is attempting to address within developing countries." Reading this statement obliges me to reconsider my previous "common sense" faith that modern technology from the Western nations is always superior to traditional ones still in use in many developing countries, and that the promotion of modern technology is universally beneficial. Wicklein cited 7 items in *Design Criteria for Sustainable Development in Appropriate Technology*.

1. *Systems-Independence* (the ability of devices to stand alone, with minimal initial investment, available supporting infrastructure, and minimal need for improvement);

2. *Image of Modernity* (the need for the technology to convey a sense of modernity, progress, and dignity);

3. *Individual Technology vs. Collective Technology* (consideration for the local societal/cultural standards, i.e., more collectivistic cultures are more suitable for "group approach" to operating larger systems; while more individualistic cultures are more responsive to stand-alone systems such as using photoelectric solar panel to provide domestic electricity);

4. *Cost of Technology* (an important factor in the design and construction of appropriate technologies for developing countries);

5. *Risk Factor* (minimization of risk of failure, including *internal risks* of not fitting the local production system, and *external risks* of dependency on outside support);

6. *Evolutionary Capacity of Technology* (the ability to continue to develop and expand beyond its originally intended function);

7. *Single-Purpose and Multi-Purpose Technology* (The possibility to be used in more than one application, or multi-functionality).

Wicklein (2008) pointed out that the appropriate technology approach "has concern for people and the environment at its center," and can "contribute to society, school aged children, and to developing nations around the world;" and placed emphasis on using renewable sources of energy and environmentally sound materials as the "crucial topic" for teaching the concept of sustainable development in the classroom. These ideas, together with the above-mentioned 7 criteria, clearly implied that K-12 engineering and technology curriculum should not be limited to teaching science, engineering and technology alone in a socially-neutral or value-less fashion, but should involve concern for the overall economic and ecological benefits of the society. Thus, technology should not be pursuit for its own sake, but rather as an instrument for satisfying human needs without damaging human habitat. Wicklein cited two case studies to support this multi-dimensional application of technology. *Case 1* (*Domestic Technologies*) illustrated how an "intermediate technologies" of "hand operated wash tub which requires only a single element from modern technology - the availability and popular pricing of detergent," to be used for laundering clothes, using locally available resources, and creating jobs, could be a reasonable substitute to physically-exhausting way of washing clothes by hand, and to expansive power-operated washing machines, in an imaginary Third World country called Macudo. *Case Study 2* (*Domestic and Commercial Technologies*) illustrated the use of photoelectric cells in low-cost operation of telephone system in Columbia, a country with mountainous topography, which makes normal telephone systems difficult to install and maintain, as well as its contribution to the growth of local photoelectric cells manufacturing companies.

Educating new generations of ethical and ecologically-conscious and yet profitable innovators and inventors

In the Age of Globalization, one of the keys to maintain American leadership in global marketplace is technological innovation, invention, design and development of new products and systems. The world is changing and America will have to change as well. With rising awareness for environmental protection through the increasing use of non-polluting and renewable energy, for economical use of exhaustible natural resources, for the protection of consumer rights, the traditional practice of engineering design for profit alone has to be replaced by a new practice where profits and justice, consumption and environmental protection must be balanced. Therefore, the new generation of engineering innovators and inventors could be expected to demonstrate the following qualities:

- National and global awareness: They should foster: (1) American patriotism, or loyalty to American people's ideals, traditions, values, interests and rights; and being willing to serve the needs of communities and of the Nation (this is very important in the Age of Globalization, when international competition is increasingly based on scientific discovery, engineering design and technological innovations; thus, awareness of the role science and technology play in national interests and national security should be fostered as well); and (2) global awareness, or an understanding of cultural diversity in the world and economic interdependence among the nations, and an open mind to absorb all beneficial scientific and technological achievements from all countries, regardless of the source.

- Social consciousness: They should understand the impact of engineering design on society, in terms of consumers' rights and interests, safety and ergonomics, and other issues.

- Ecological stewardship: They should understand the impact of engineering design on environment, in terms of designing products and systems that consume as little natural resources as possible, that could be built using as non-polluting as possible manufacturing processes, and that are as multi-functional, space-saving and energy saving as possible. Other issues such as retirement, recycling and disposal of the products and systems should also be understood. *Figure 9* through *Figure 11* shows examples of such products and systems.

- Academic excellence: They should master the fundamentals of mathematics, science and engineering, in terms of analytic and predictive abilities, as well as digital modeling and simulation skills.

- Innovative and creative abilities: They should be familiar with the engineering and technology design process, be able to integrate the fundamentals of science and engineering from different fields, to define, analyze and solve design problems with alternative solutions, and to choose the most innovative and functional design solution.

- Entrepreneurial initiative: They should understand the way America's socially-regulated free enterprise works, the issues of ethical and yet profitable management, of risk-taking in research and development, of protection for intellectual property rights, and others.

- Economic sense: They should understand the issue of cost-effectiveness in the manufacturing and construction process as well as in maintenance, of affordability for end-users, in addition to a reasonable profit margin.

- Synthesizing ability: They should be able to understand the social and technological environment from different philosophical perspectives, and to come up with their own ethical and workable design solution.

The courses in the proposed K-12 Engineering and Technology Teacher Education programs are aimed at preparing the next generations of K-12 educators that could help high school graduates to achieve the above qualities.

Figure 9. Space-saving foldable car using three types of energy source (battery, biofuel, and gas) invented by David, a British inventor in his 30s (International Online, December 17, 2008. Retrieved January 31, 2009, from http://www.chinataiwan.org/tp/jctp/200812/t20081217_799528.htm).

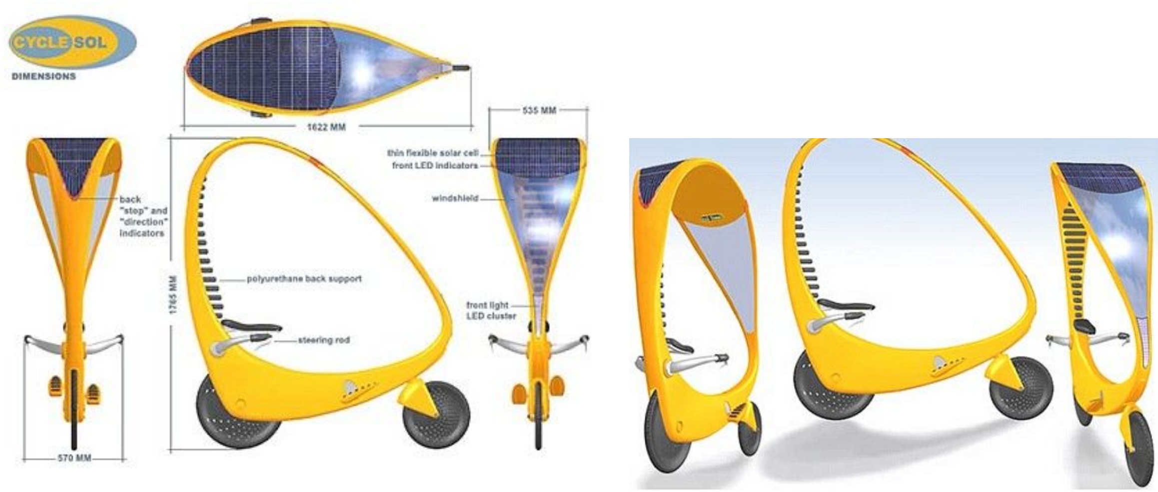


Figure 10. Bicycle using solar energy invented in Britain (China.com.cn, September 29, 2008, from http://www.china.com.cn/tech/txt/2008-09/29/content_16554257.htm)

Figure 11.Solar-powered building that can rotate on wheals and tracks, invented by Hamilton, a British inventor (BBC Chinese, April 13, 2007. Retrieved January 30, 2009, from http://news.bbc.co.uk/ hinese/trad/hi/newsid_6550000/newsid_6554500/6554549.stm)

Limitations on expected outcome

Our expectations for K-12 students should not be to train them to become instantaneous robotic designers or spacecraft engineers (although we should give the academically highest achieving among them an adequate preparation for these careers of vital national interests); this is generally beyond their cognitive maturity (except in some high-achieving communities where economic and educational conditions might magically allow this to happen); instead, we should aim at matching K-12 engineering and technology education with the cognitive maturity of K-12 students. Taking the Mechanical Engineering *Career Pathway* as an example, they could be expected to graduate from the program with some creative abilities and analytic skills to design and prototype everyday products or systems, with simple mechanical and electronic components (either of their own design or from out-of-shelf selection), which are professionally ready for production or installation; and these could include toys, utensils, furniture, clothing, and fastening devices. This might be doable for average high school graduates. But they should not be expected to design robotics except the very simple ones using out-of-shelf components. Expecting too much from K-12 students without a reasonable chance to succeed would not be the best way to prepare them for a brilliant engineering career. This line of thinking is compatible to the "everyday technology" idea of broadly defining "the term technology to include the artifacts of everyday life as well as environments and systems," of "focusing on the technologies of everyday life," and of allowing children to "solve problems of real significance in their lives," which have been explored by Benenson and the 10-year long City Technology project (2001. pp. 730-732).

Potential contribution of the proposed model

By eventually achieving a streamlined engineering and technology education process across K-12 and collegiate levels, the proposed model might make a contribution to increased enrollment of domestic American students in science, engineering and technology majors, solve the problem of chronic shortage in these areas of vital national interests, and preserve American leadership in these important areas in the Age of Globalization. In world history, there are plenty of evidence that the ratio of scientists and engineers per population greatly contributes to any country's strength and positions in the world. For example, after World War Two, many more top scientists and engineers from former Nazi Germany freely immigrated to the United States than have been forced to move to the former Soviet Union; and this contributed to making America the leading scientific power in the whole world and to the survival of the Free World from Soviet threat. Another example is Israel; for every 10,000 citizens, there are 140 scientists and engineers (this ratio is twice as great as those of the United States and Japan, and the highest in the whole world); thus, within a short span of 50 years, Israel became a strong nation in Middle East, and one of the major scientific and technological powerhouse in the whole world (anonymous, 2007).

Part Five

Making Design the Integrating Factor Linking Engineering and Science Through High School Engineering and Technology Program

As mentioned before, Wicklein (2006, p. 25) proposed design as the integrating factor linking engineering and science through high school technology program. *Table 10* illustrates Wicklein's hypothetical high school curriculum plan that is divided into "lower end" and "top end," and could sequence its technology education program, in such a way that it could "allow for both a general education and a career and technical education application" and "provide a balanced curriculum for all students, whatever their career path may be" (2006, pp. 25-28). Infusing design into high school mathematics and science curriculum would make them more relevant to real word scenario; and increase student interests in the subjects, which would otherwise appear too "theoretical."

Table 10. Engineering-Focused Curriculum for High School

Lower end of the curriculum: The program would be inclusive and open for all students at any academic level ("general education")			
Technology Education	**Mathematics**	**Science**	**Foreign Language**
Engineering Concepts	Algebra I	Biology	Foreign Language I
Engineering Graphics (CAD)	Algebra II	Chemistry	Foreign Language II
Top end of the curriculum: The program would be more exclusive and open to students who have achieved appropriate academic prerequisites in technology, mathematics, and science courses (career and technical education).			
Technology Education	**Mathematics**	**Science**	**Foreign Language**
Research & Design	Geometry or Trigonometry	Physics	
Engineering Applications	Trigonometry or Calculus		

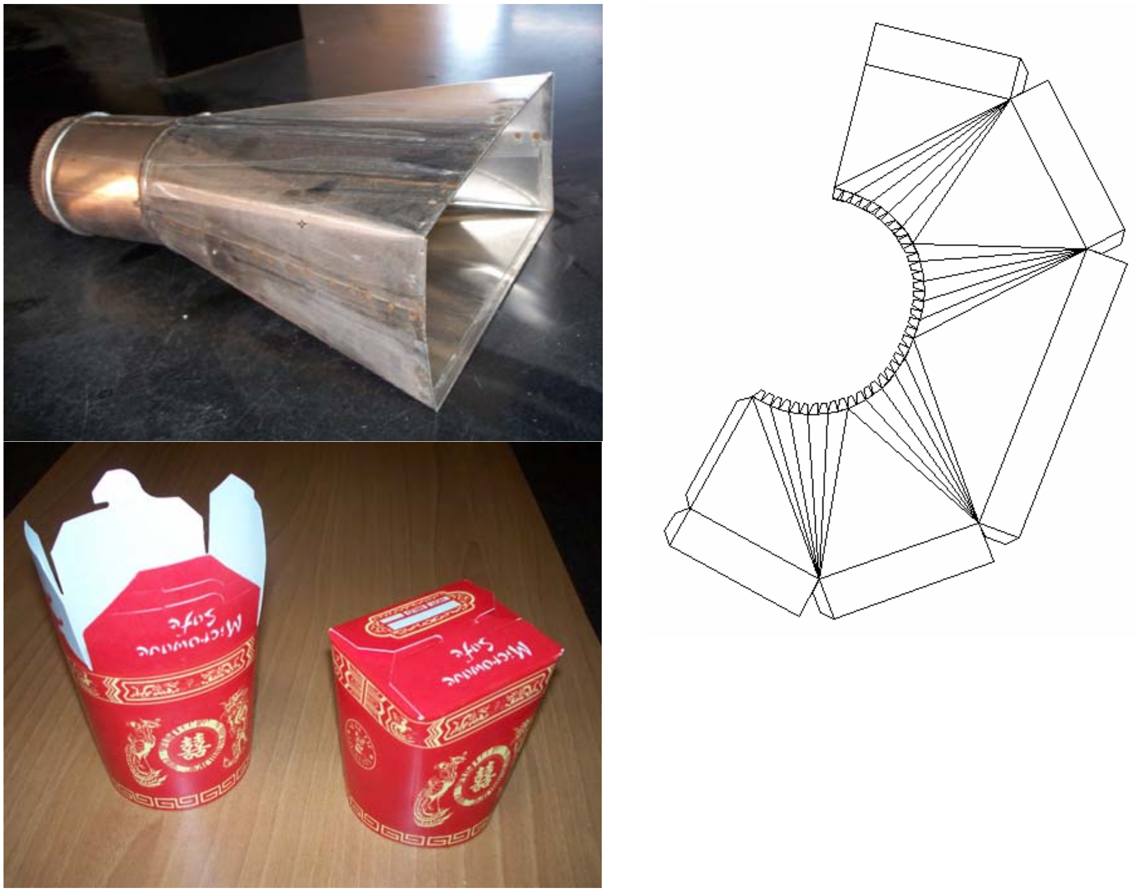


Figure 12. Examples of circle-to-square transition pieces (sheet-metal connector and restaurant take-home food container)

Lewis (2007, p. 846) indicated that, “to become more entrenched in schools, engineering education will have to take on the features of a school subject and argued in terms of what is good for children;” furthermore, it would not be very practical to overburden the already crowded K-12 curriculum with too many stand-alone engineering *Career Pathway* courses. Therefore, Wicklein’s idea of integrating high school engineering and science curriculum through design is a practical one. Two approaches could be considered for the implementation of this idea.

1st approach (a moderate approach): Infusing engineering and technology topics into K-12 mathematics, physics and chemistry courses

In addition to teaching engineering analysis and design through special *Career Pathway* courses, suitable engineering knowledge contents could be incorporated into regular mathematics, chemistry and physics courses, as extra teaching materials, word problems, and simple design projects. For example, in Geometry course, the engineering application of the triangular shapes could be explained to students (triangle is “indestructible,” unless the side lengths are changed, the shape would stay intact; thus, triangular members are widely used in structural design; bridge design projects could be incorporated, with learning materials from the Internet, to study the subject of force equilibrium, to simulate bridge design with West Point Bridge Design software (http://bridgecontest.usma.edu/), and to build a scaled model. In addition, because triangles have one straight edge opposite a sharp corner, they can accommodate different shapes in three-dimensional space and are used in the development of irregular or curved surfaces; thus, some topics of engineering sheet-metal design could be taught, giving the students an opportunity to design a transition piece, such as shown in *Figure 12*. In Chemistry course, subjects of material selections could be incorporated. Other appropriate engineering topics could be identified by engineering and technology faculty and graduate students using well-established criteria, and gradually added to regular K-12 mathematics, physics, and chemistry courses as extra learning materials, through a process of pilot study and other mechanism of pedagogic experiment. This approach is simple, easy to implement and virtually risk-free and would not cause any controversy or political opposition.

2nd approach (a drastic approach): Decomposing mathematics, physics and chemistry courses into modules and incorporating them into an integrative STEM curriculum throughout K-12 education

This approach would better reflect the idea of using design as the integrating factor linking engineering and science through high school technology program (“unified curriculum framework”) proposed by Wicklein (2006, p. 25) and Rojewski and Wicklein (1999). Using this approach, K-12 mathematics, chemistry and physics courses would be decomposed into smaller modules relevant to engineering analysis and design, and to traditional and modern technology; and then the modules would be incorporated into K-12 engineering and technology curriculum, to merge the two sides into a totally integrative STEM curriculum. At Virginia Institute of Technology, Dr. Mark Sanders pioneered the integrative STEM experiments, which is to certain degree similar to this approach. According to Sanders (2008, pp. 1-2), the notion of integrative STEM education “includes approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more example, cannot be separated from social and aesthetic contexts, neither should the study of technology be disconnected from the study of the social studies, arts, and humanities.” Mativo’s Animotronics design project (Sirinterlikci and Mativo, 2005), using “mini lessons” to deliver STEM course content could also be used to build a hypothesis that this approach might work. Wicklein also indicated that this 2nd approach could possibly work (advisory meeting, February 6, 2009, 4:00PM). In my opinion, this 2nd approach might be an ideal one for long-term consideration; however, it is obviously a drastic alternative to the proven pedagogy for mathematics and science at K-12 level; and although it might be doable, further pedagogic experiments through pilot studies would be warranted to make sure that it actually could work. In addition, there might be some political obstacles to overcome in order to implement this approach even if pilot studies show that it could actually work.

Part Six

Feasibility of the Proposed Model

The idea of a streamlined engineering and technology education from K-12 to university Bachelor of Science degree and beyond might be feasible. The proposed model of infusing engineering design into K-12 curriculum includes four stages: (1) Kindergarten to elementary (Grades K-5): Conceptual design using "brainstorming sessions," educational entertainment and others, and based on broad exposure to a variety of science, engineering and technology subjects, with light inclusion of engineering analytic and predictive skills; (2) Middle school (Grades 6-9): Engineering design based on experiments, using mainly the Technology Education Process; (3) High school (Grades 9-12): Simple design projects using "Analytic Reduction" model for solving well-structured engineering design problems, focusing on scientific and technological issues, throughout well-designed high school engineering analysis courses; and (4) High School graduation year (Grade 12): Complex engineering design using "Systems Thinking" model, solving ill-structured and open-ended problems, integrating scientific and technological issues with social, cultural, economic and ecological factors, in "Capstone" engineering design courses. Clearly, the proposed model takes a cautious, moderate, incremental methodical approach in building up K-12 students' engineering and technology arsenals, taking into careful consideration the average cognitive developmental levels of American K-12 students, advocating minimal but achievable standards for average K-12 students, while promoting rooms for further growth for the academic high achievers. The assumption that the proposed model could be supported by the pioneering experiment of Duke University Pratt School of Engineering, one of the leading institutions of engineering education in America. Actually, compared to Duke University experiment, the proposed model's expectations of K-12 students' engineering analysis and design potential would be on the conservative side, which might allow the proposed model to be implemented in school districts with average academic achievements.

For many years, Duke University Pratt School of Engineering has pioneered an unique Engineering K-PhD program based on the revolutionary idea of starting engineering education from kindergarten and up, not after the start of the high school, with a mission "to increase significantly the number of children, particularly female and under-represented groups, who choose to pursue science related careers." The program "provides opportunities for children to learn to think critically and analytically while developing a passion for understanding the world and an appreciation for improving the quality of all living things." (Duke University, 2009). For years, the program has taught K-8 children many science, engineering and technology topics, under the motto of "Hands-On Exploration of Technology in Everyday Life," including AM Radios, Biomedical Devices, Bridges, Heart Monitors, Lego Robotics, Mars Rovers, Solar Energy, Towers and Techtronics, which integrate STEM with hands-on engineering education. Science and engineering curriculum are well-designed to match children's cognitive development level, using student-centered pedagogy, and children-friendly tools such as Lego educational toy kits; for example, Lego Robotics lessons use Lego Mindstorms Kits and feature two projects: (1) Lego Maze Solver Project: This project introduces computer and mechanical engineering concepts as students use components from Lego Mindstorms Kits to design and build robotic cars to navigate a maze with all 90 degree turns, teaching students about basic computer programming, robots, sensors, gear ratios and engineering design, covering one concept per week to gradually build up mechanical engineering analysis, component selection and design capability. (2) Creative Lego Robotics Project: "In this project, teams of 2-3 students are given the task of building and programming any kind of robot using the Lego Robotics kits. Some students thrive and come up with very exciting projects provided this open ended problem while others are unsure how to proceed," and for the later, Fellows from Duke University provide some suggestions based on past projects. For the students who have lots of ideas, the Fellows coach them on deciding which direction to pursue further. This is a student-centered pedagogy that allows upward mobility of academically advanced while promoting basic equality in standard academic achievement by helping the academically disadvantaged to catch up (Techtronics, 2009).

Streamlining the whole engineering education process from K-12 to four-year universities, by a fully-integrated and cross-institutionally articulated curriculum, with rationally and clearly defined goals for all stages, and with flexible knowledge content transfer mechanism, as illustrated in *Figure 4*, should be doable in my opinion, based on the following feasibility notes:

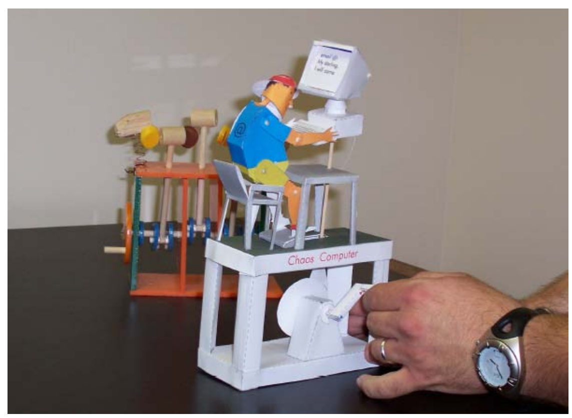
1. Matching children's cognitive maturity with creative pedagogy

- At ages 3 and 5: Previous research project conducted by Fleer (2000, p. 47-58) and funded by the University of Canberra and the Curriculum Corporation of Australia for the development of a technology curriculum concluded that children as young as 3 years of age can engage in oral and visual planning as part of the process of making things from materials; and that their planning involved the use of lists and designs of what they intended to make. Most of the children were able to make the conceptual leap from oral planning to 2-D designing, predominantly with front views. The research involved children aged 3 to 5 years (a total of 16 children from a middle class background who attended a child care center in the Australian capital, using video and audio recordings over two weeks). In the project, the teacher told the children a story about a mythical creature that she had found in her garden, and asked them to create a friend for the lonely creature; the results indicated that "when children are given the opportunity to see the purpose of design work through being shown architectural plans and are supported in their drawing of plans (through the teacher modeling her design work and then building from blocks her design), children's drawing capabilities in representing plan-views markedly changes."

- At ages 5 - 7: Studies conducted in a Swedish elementary school located in a suburb approximately 10 km south of downtown Stockholm with a large immigrant population ("98% of the housing consists of low-income rentals and approximately 50% of the students have a first language other than Swedish) indicated that "students as young as 5 to 7 years old" can engage in simple invention activities such as creating a new type of sandwich, using design journals to record creative thoughts (Druin & Fast, 2002, pp. 192-194). Claxton et al (2005, p. 328) indicated that the level of developmental maturity occurred around 5 to 6 years of age; that a creative peak occurred at 10 to 11 years old; and that "after age 12, a gradual but steady rise in creativity occurred through the rest of adolescence until a second peak was reached around 16 years of age (Claxton, Pannells, & Rhoads, 2005, p. 328). Mativo's *Beep Beep Zoom: Relationships Among Technologies - Grade Two - Interdisciplinary Lesson* (available for download at the Website of Ohio Department of Education at http://ims.ode.state.oh.us/ODE/IMS/Search/GSASearchResults.asp), is a good example of exposing Grade 2 pupils to a broad range of engineering and technology topics, through well-integrated, cross-disciplinary learning activities. The lesson is designed to be delivered in Five days, 50-minute blocks, and allows students to observe and investigate relationships between technology and associated artifacts (such as transportation systems with bridges, ambulance, cement mixer, ice cream vehicle, fuels, coolants, and engines; mechanical and civil engineering, etc.), related scientific concepts (such as power), and professions (such as dealership and salesperson, design engineer, geologist, etc.), and constitutes an elementary school version of a typical introduction to engineering course offered in undergraduate engineering program.

- At ages 7-12: Previous experience by Sirinterlikci and Mativo (2005) indicated that secondary school students could handle engineering design activities in an inter-disciplinary setting. In their endeavors at developing a cross-disciplinary study involving engineering, technology and art for undergraduate students, by enhancing the Mechatronics and Robotics Program at Ohio Northern University Technological Studies Department, Sirinterlikci and Mativo (2005) developed the inter-disciplinary, open-ended and creativity "Animatronics" honors course with toy and entertainment design, which use the design of life-like entertainment robots or dynamic and interactive animated toys (animated mechatronic blob, penguin, robotic trash can, and a human/monster hybrid, which could cruise, wave their swords, flip their wings and light their eyes), in a fun and creative team environments, to combine analytic and design skills from several different but interconnected fields: (1) mechanical engineering (material and manufacturing process selection including metals, ceramics, plastics and composites, mechanism design and assembly of levers and cranks, etc.), (2) electronics (actuators, sensors, controls), (3) microcontrollers structure and programming, (4) emerging technologies such as muscle wires, air muscles, micro- and nanocontrollers, (5) two- and three-dimensional art (costuming from fabrics to rubber Latex, and modeling), and (6) industrial product design. With the completion of the honors course, Sirinterlikci and Mativo developed an NSF (National Science Foundation) proposal based on the same approach utilizing animatronics for a grades 7-12 project. It is a weekend program complemented by a summer capstone experience. Since then the authors has gained recognition and partners leading to funding of two small projects by Ohio Northern University and a major summer program for gifted and talented secondary school students by Ohio Department of Education. A three-day summer camp was also designed and successfully executed with participation of four local middle school students from the gifted and talented program. During the development stage, the authors have interacted with an art professor to strengthen the art component of the program. With this help, new modeling materials such as oil based clays were used in addition to earth based clays, urethane and other polymers. Sirinterlikci and Mativo's pedagogic experiment indicated that learning engineering design help high school students to increase interests in STEM and academic success (see *Figure 13* for details).

Modeling with polymer based clays

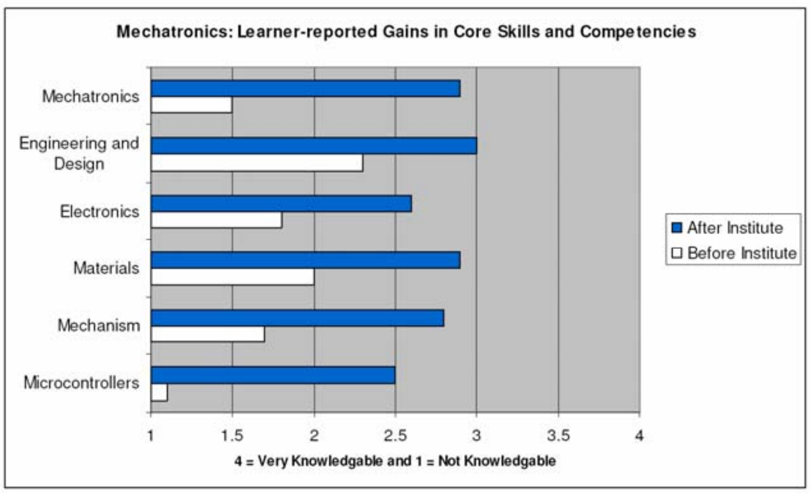


Mechanism design

Figure 13. Sirinterlikci and Mativo's successful Animatronics project (Sirinterlikci & Mativo, 2005).

Reverse engineering: dissecting a mechatronic ladybug

My collection of animatronics toys. The cat's eyes have sensors that can respond to waving hands.

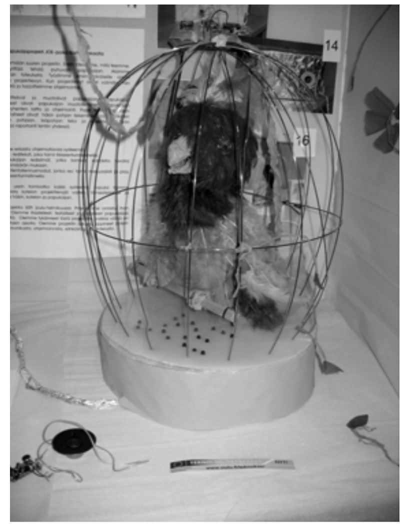


High school students improve STEM learning through inclusion of engineering design.

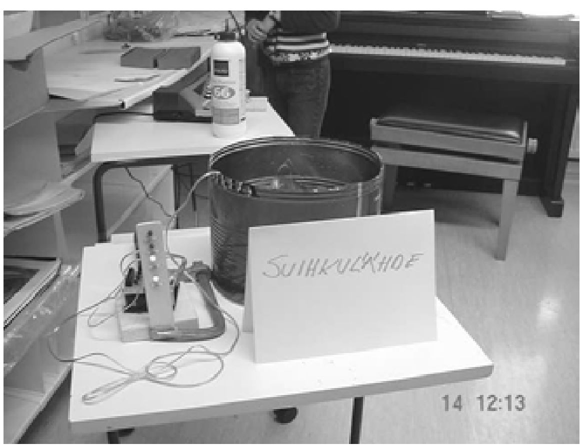
Figure 13. Continued.

- <u>At ages 11-14:</u> Study by Järvinen, Karsikas, and Hintikka (2007, pp. 48-50), conducted during school years 2003-2005, with twelve comprehensive (primary and secondary) school classes of grades 5-8 (ages 11-14 years) in Finland, using the Picaxe-08 microcontroller system, with components such as light emitting diodes (LEDs), buzzers, lamps, motors, sound recording modules, miniature water pumps, as well as sensors such as various kinds of switches, passive infrared sensors (PIRs) as well as negative temperature coefficient (NTC) thermistors and light dependent resistors (LDRs), which was developed in England by Revolution Education Ltd. (www.rev-ed.co.uk/picaxe) and modified collaboratively with a Finnish company, Step Systems Ltd., indicated that "children could design, make, and program an application rising from their own ideas and needs;" and "have very fertile minds for coming up with unique ideas," dealing with open-ended design problems "whose final product was not known by anyone at the start of the project;" and that "innovation is not just something carried out in the research and development laboratories of large technology industries, but all of us, including children, can be innovators." (See *Figure 14* for details).

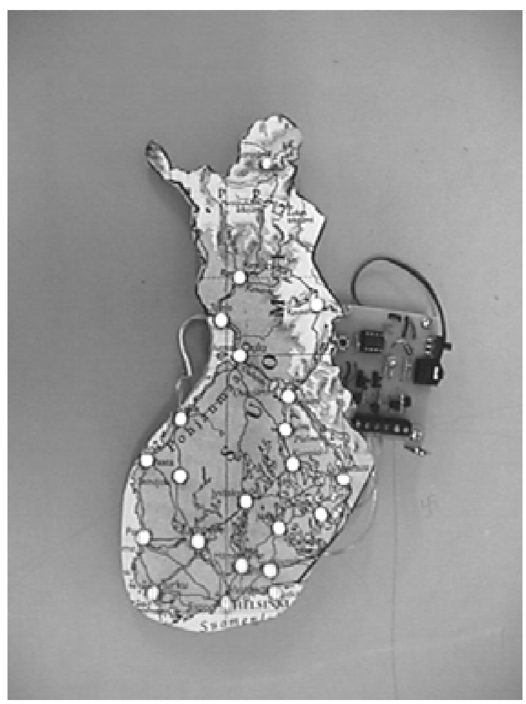
Amusement Park.



Water fountain.



Water fountain



LED map of Finland.

Figure 14. Finnish grades 5-8 electronics design project.

2. Facility sharing: Sharing laboratory facilities between high schools, two-year community colleges and four-year universities could make engineering and technology education more cost-effective. This has been done in many places.

- Between two-year college and four-year university: Los Angeles Trade Technical College has been sharing material testing facility with California State University for many years.

- Among high schools: Regional Occupational Centers in California allow students from different high schools to share same facilities for technology-related courses.

Part Seven

Available Pedagogic Resources for the Implementation of the Proposed Model

Should we use the gear train as an analogy for the proposed model, then there should be no need to reinvent the gears or even to redesign them; our task is to rearrange the positions of the available types and sizes of gears, and to design our own linkages and functional components to be driven by the gear train, so that the various gears we choose would be able to perform our intended functions; and the essential components of the proposed model would be analogous to these linkages and functional components.

In terms of the logistics to support our campaign of infusion engineering design into K-12 curriculum, a lot of pedagogic resources, such as lesson plans, instructional materials, STEM simulation software, and a variety of others, which are specifically designed for all stages of K-12 curriculum, have been already made available through the efforts of generations of educators, government agencies, private businesses, and non-profit organizations (refer to Appendix E). These pedagogic resources have already covered the fundamentals of engineering and technology topics that are appropriate for K-12, especially the kindergarten, elementary and middle school stages; and they have provided workable formats for the development of additional pedagogic resources, which would be more specifically intended for high school (grades 9-12) engineering and technology *Career Pathways*. Current and future K-12 educators could selectively use the currently available pedagogic resources and create more according to the changing conditions of the time.

For the full implementation of the proposed model explored in this paper, what K-12 engineering and technology teachers might consider is probably the development of more engineering-specific instructional materials, which should cover high school appropriate topics in engineering analytic courses (such as mechanism design and mechanical component selection, circuit analysis and electronic component selection, strength of materials and materials selection, statics and dynamics, fluid mechanics and others).

Part Eight

The Potential Value of the Proposed Model: The Fundamental Differences between the Proposed Model and the Existing Programs

Gattie and Wicklein (2007, p. 6) pointed out that "current efforts at the University of Georgia propose adjusting the focus of Technology Education to a defined emphasis on engineering design and the general process by which technology is developed. Such an emphasis has the potential for providing a framework to: (1) increase interest and improve competence in mathematics and science among K-12 students by providing an arena for synthesizing mathematics and science principles, and (2) improve technological literacy by exposing students to a more comprehensive methodology that generates the technology. This will inherently raise mathematics and science requirements for technology teachers and technology teacher educators. Moreover, general textbook and instructional material needs for teaching technology education with an engineering design focus will undergo change." In addition, Gattie and Wicklein (2007, p. 7) proposed that "the field of technology education as fertile ground for developing an institutional, systemic approach to the needed synthesis of science, technology, engineering,

and mathematics (STEM) in K-12 education, citing study by Dearing and Daugherty (2004) which indicated that "current issues of concern for the overall academic K-12 education subjects have developed due to low nationwide performance in mathematics and science subjects, and a general absence of K-12 programs that motivate and prepare students to consider engineering as a career option;" and according to Gattie and Wicklein, "recently, the field of technology education has attempted to address these concerns by incorporating engineering concepts into its educational schema, thereby providing a formal structure for synthesis of science, mathematics, and technology."

The proposed model is presented in response to this call for change in mind.

Major differences between the proposed model and existing programs

Per advice from Dr. John Mativo, Professor of Engineering at College of Education, the University of Georgia, on January 28, 2009, I have thought over the justifications for presenting the proposed model, in terms of its relationship with the existing programs. Many models of K-12 engineering and technology programs have been promoted throughout the United States for many years with varying degrees of success. My proposed model would be built on their successful experience. However, there exist some major differences between the existing programs and my proposed model:

1. Program classification and societal needs: The existing technology education programs, including the one at the University of Georgia and others at the University of Minnesota (http://onestop2.umn.edu/programCatalog/ viewCatalogProgram.do?programID=45) and Utah State University (http://www.ete.usu.edu/ete.htm#trade), tend to be more focused on technology as an appendage of engineering (thus the name of K-12 Technology Education) instead of embracing hard-core engineering as a major theme; the current programs historically have reflected and served America's past needs for a technology-literate workforce, but do not seam to adequately meet today's global challenges. The proposed model would switch the balance to the hard-core engineering design side, looking forward to meet the new challenges of Globalization and its economical ramification for local, national and international communities in the 21st Century (in terms of outsourcing of lower-end technical employment to developing countries, etc.), and training greater number of higher quality domestic American innovators and inventors who could secure America's leading position in science and engineering with a stronger and more creative professional workforce; and therefore, securing America' leadership in international economic development. As mentioned before, leading researchers within and without the field of K-12 Technology Education have pointed out inadequacies of current curriculum and proposed reasonable remedies, such as Wicklein's idea of integrating STEM with engineering design, Lewis' advocacy of codification of K-12 engineering analytic knowledge content, Mativo's development of high school engineering lessons (available for download from http://www.coe.uga.edu/welsf/faculty/mativo/index.html, in the "Publications" section). All of the above indicated a need to strengthen engineering predictive analysis courses - as opposed to trial and error methods of design in problem solving issues as practiced today - in K-12 technology teacher education programs at university undergraduate level, as well as in the future K-12 engineering and technology curriculum, especially at high school level. This need would be met by the proposed model.

2. Program scope: Existing programs tend to treat K-12 engineering and technology subjects in a more-or-less "piece-meal" fashion, while the proposed model would take a more systematic and cohesive approach with codification of K-12 engineering and technology knowledge content, to be taught and learned through an integration of three approaches: (1) Traditional analytic methods using mathematics-based formulas; (2) Traditional laboratory experiments; and (3) Digital simulation; in addition, the proposed model differentiate the infusion of engineering design into four stages, according to students' grade levels. The idea of "integration of three approaches" is in line with previous scholarly exploration. Citing materials course required by Industrial Technology curriculum as an example, Mativo (2005) recommended a "balanced combination of the two components" (the "theoretical" and the "practical") plus utilization of software in material selection (in the case of materials science, the CES software,

http://www.grantadesign.com/company/), as "critical to the understanding and utilization of materials," for the ultimate learning experience. This idea could be applied to any high school engineering course; the "theoretical" part (traditional analytic and predictive skills using math-based formulas), the practical" part (corresponding to traditional physical laboratory experiments), and computer simulation software could be integrated to give students a comprehensive tool set for solving engineering analysis and design problems.

3. <u>Program status</u>: Existing programs tend to be more "after-school science enrichment" or "curriculum enhancement," or at most "pre-engineering" programs, rather than fully-developed and cohesive "K-12 engineering and technology" programs as an integral part of the whole K-12 curriculum. The proposed model would make engineering and technology education an integral part of the K-12 curriculum. Under the proposed model, the currently existing programs, such as Project Lead the Way, the Animatronics program developed by Dr. John Mativo at al (Mativo, 2005) would continue to operate as part of the "regular' K-12 engineering and technology curriculum, or as science and engineering enrichment programs to provide K-12 students opportunities to synthesize the analytic content knowledge they would learn from regular K-12 engineering and technology courses, and to solve open-ended engineering design problems under the guidance of instructors or volunteer professional mentors.

4. <u>Program outcome</u>: Existing programs tend to be aimed more at improving STEM scores for high school students, with the inclusion of engineering as an instrument rather than an ultimate goal per se. The proposed model would reasonably expect graduates from K-12 engineering and technology programs to be well-prepared for (1) "Streamlining" into university undergraduate science and engineering programs, with portions of pre-calculus level engineering analysis skills, some of engineering technology (CAD/CAM, digital simulation), as well as basic engineering design process mastered (in my opinion, the highest achieving students should be encouraged to take this route); and (2) Entering college level engineering technology majors (in my opinion, the average high achieving students could consider this route); and (3) Entering other college majors, or engineering technology-associated workforce (CAD drafter, etc.), with the abilities to design and to construct simple but fully-functional products and systems, such as furniture, tools, toys with electronic devices, household and community energy systems (in my opinion, less than high achieving students could consider taking this route). However, the opinions expressed here are nothing more than convenient suggestions, and by no means constitute any intended objective of the proposed model. In fact, should the proposed model be adequately implemented, then all students (highest or less than high achievers alike), could be better prepared for a science or engineering major at college level, than under the currently existing programs. Therefore, the proposed model should be an upward mobile model that promotes equal preparation for

college engineering majors from an academic perspective; no tracking is involved, and it would be up to the students to choose their career paths. Apparently, not all K-12 graduates will enroll in college engineering majors. *Figure 15* illustrates some possible relationships between academic achievements in both "Engineering and Technology Main Courses" and "Integrated STEM enrichment" activities, and possible choices on continuing education or entry into the employment market.

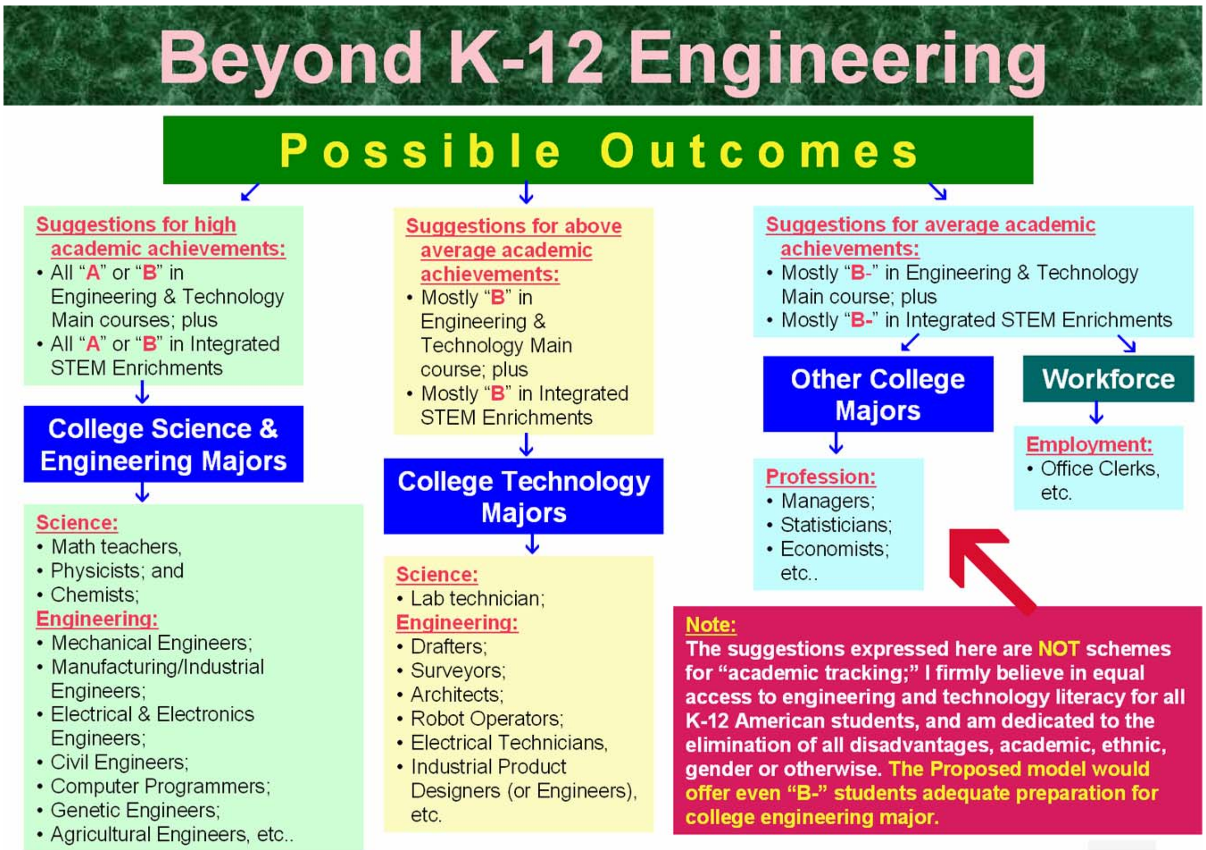


Figure 15. Possible outcomes when K-12 students graduate from high school (not a suggestion for "tracking").

5. Program flow: Existing programs tend to be using solely integrative STEM approach throughout the entire K-12 curriculum, without differentiating engineering design approach into incremental stages that match K-12 students' ages. This integrative STEM approach works to varying extent in diverse school districts with varying degree of academic success. The proposed model takes into consideration the needs of both average achieving and high achieving school districts, by differentiating engineering design process into four different stages (or an "linearly incremental four-stage model"), each matching a stage in K-12 education (i. e., kindergarten to

elementary or grades K-5, middle school or grades 6-8, high school or grades 9-11, and finally, high school graduation year or grade 12); this could make it easier for average achieving school districts to implement engineering and technology curriculum; this could ensure an incremental and solid mastery of basic engineering analysis and design literacy for all American K-12 students. On the other hand, the proposed model would give high achieving students in all school districts opportunities to dive deeper into the great ocean of engineering design, using interdisciplinary engineering analysis and design projects with integrated design approach and "system thinking" model (a "recursively systemic model"), such as previously discussed "Animatronics" project developed by Mativo and Sirinterlikci (2005), or Project Lead The Way; the implementation of these challenging design projects as academic enrichment activities, in K-8 extracurricular activities, summer camps, or high school capstone engineering design course, could help promoting academic excellence for outstanding K-12 students. Both "linearly incremental four-stage model" and "recursively systemic model" could work recursively and harmoniously, with the later serving as an opportunity to review and reinforce all relevant STEM knowledge content as well as the design skills gained in the former. Therefore, the proposed model reflect the democratic and progressive values of mainstream American educators, and could be implemented as a holistic, student-centered, industry-serving, well-balanced new paradigm that combines basic academic equality and accessibility for all plus flexible upward mobility for a potentially growing number of high achievers, in the field of engineering and technology.

6. <u>Program curricular structure</u>: As shown in *Figure 16*, the proposed model clearly delineates the engineering and technology courses that K-12 students could take at each stage of their academic journey (existing programs do not go into these well-organized and well-defined details):

    - <u>Kindergarten to elementary (grades K-5)</u>: Three courses would be offered in sequence, each taking two years to complete: (1) Introduction to science; (2) Introduction to Technology; and (3) Introduction to Engineering. These courses would launch pupils to science, engineering and technology orbit right at kindergarten level, exposing both little girls and boys to a wide variety of science, engineering, and technology topics, including the conceptual and creative design process (with a light inclusion of analytic and predictive skills where applicable). This is equivalent to allow the K-5 pupils to complete the college-level Introduction to Science, Engineering and Technology, plus K-12 appropriate portions of Engineering Ethics, Appropriate Technology, Technology in Society courses, building a broad knowledge base on technology applicable to daily life. This stage would lay a solid foundation in creativity for little girls and boys.

- Middle school (grades 6-8): Three courses would be offered, each taking one year to complete: (1) Drafting; (2) 3D Modeling; (3). Power and Energy; (4) Construction System; (5) Manufacturing System; and (6) Electrical Circuitry and Component Selection. These are similar to traditional technology courses that up to this point are offered in typical K-12 technology curriculum. Traditional laboratory experiment and modern science and technology digital simulation software would be covered in these courses as well as in mathematics, physics and chemistry courses. This stage would build a solid and meaningful foundation of engineering related technology, which could be regarded as a pre-engineering preparation to entry into hard-core K-12 engineering at high school level.

- High school (grades 9-12): Six courses would be offered, each taking one semester to complete. Three of them are Engineering Foundation courses: (1) Statics & Dynamics; (2) Material Strength & Selection; and (3) Heat Transfer & Thermodynamics, or Fluid Mechanics & Aerodynamics. Another three courses are Engineering Major (or "Career Pathway") courses, in Mechanical Design, Electronics, Civil Engineering and Construction, and other fields. The remainder two courses are Graduation Year Engineering Design "Capstone" courses (grade 12), which correspond to typical Senior Year Design courses required by Bachelor of Science in Engineering degrees, but at high school or pre-calculus/beginning calculus level, satisfying realistic expectation for practical and functional design outcome.

The above major differences between the proposed model and the existing programs are summarized in Table 11.

Table 11. Major Differences between the Proposed Model and the Existing Programs

Major Difference	**Proposed Model**	**Existing Programs**
Program Classification and Societal Needs	More focused on technology as an appendage of engineering; reflected and served America's past needs for a technology-literate workforce.	Switching to the hard-core engineering design, looking forward to meet the new challenges of Globalization and its economical ramification for local, national and international communities in the 21st Century by training greater number of higher quality domestic American innovators and inventors.
Program Scope	Treating K-12 engineering and technology subjects in a more-or-less "piece-meal" fashion. Does NOT differentiate the infusion of engineering design into age-appropriate stages.	A. More systematic and cohesive approach with codification of K-12 engineering and technology knowledge content: (1) Traditional analytic methods using mathematics-based formulas; (2) Traditional laboratory experiments; and (3) Digital simulation; B. Differentiating the infusion of engineering design into four stages, according to students' grade levels.

Table 11. Continued.

Major Difference	Proposed Model	Existing Programs
Program Status	More "after-school science enrichment" or "curriculum enhancement," or "pre-engineering" programs than engineering per se.	Fully-developed and cohesive "K-12 engineering and technology" programs as an integral part of the whole K-12 curriculum.
Program Outcome	Aimed more at improving STEM scores for high school students, with the inclusion of engineering as an instrument rather than an ultimate goal per se.	Expecting graduates to be well-prepared for (1) University undergraduate science and engineering programs, with portions of pre-calculus level engineering analysis skills, of engineering technology and basic design process mastered; (2) College level engineering technology majors; and (3) Other college majors, or technology-associated workforce, with the abilities to design and construct simple but fully-functional products and systems.
Program Flow	Using solely integrative STEM approach throughout the entire K-12 curriculum, without differentiating engineering design approach into incremental stages that match K-12 students' ages.	1. For both average and high achieving school districts, by differentiating design process into four different stages, each matching a stage in K-12 education; ensuring an incremental and solid mastery of basic engineering analysis and design literacy for all American K-12 students. 2. "Enrichment programs" for higher-achievers. (Dr. John Mativo's "Animatronics" projects, etc.).
Program Curricular Structure	Does NOT clearly delineate the engineering and technology courses that K-12 students could take at each stage of their academic journey.	Clearly delineating K-12 engineering and technology courses at each stage K-12 journey: 1. Kindergarten to elementary (grades K-5): (1) Introduction to science; (2) Introduction to Technology; and (3) Introduction to Engineering. → Introduction to science, engineering and technology. 2. Middle school (grades 6-8): (1) Drafting; (2) 3D Modeling; (3). Power and Energy; (4) Construction System; (5) Manufacturing System; and (6) Electrical Circuitry and Component Selection. → Engineering technology or pre-engineering. 3. High school (grades 9-12): (1) Statics & Dynamics; (2) Material Strength & Selection; and (3) Heat Transfer & Thermodynamics, or Fluid Mechanics & Aerodynamics. Three courses in Engineering Major (or "Career Pathway"). Two courses as Graduation Year Engineering Design "Capstone" (grade 12). →High school engineering curriculum

Summary and Recommendations

In this paper, the following have been explored:

- The disconnections among the current requirements and expected qualifications of available K-12 technology teacher education programs, the actual expected needs of K-12 engineering and technology programs for well qualified teachers in the years to come, and the needs of university undergraduate engineering majors for well-prepared high school graduates;
- A proposed K-12 Engineering and Technology Teacher Education program, with a particular version for the University of Georgia, and a general version for the National Center for Engineering and Technology Education, and one version for California State University Los Angeles, all incorporating engineering analysis and design as vital components, for the purpose of removing the above-mentioned disconnections;
- The methodologies for infusing engineering analysis and design throughout the proposed K-12 Engineering and Technology Teacher Education program;
- The ultimate expected outcomes of the proposed program, which is to streamline the entire engineering and technology education process across K-12 and collegiate levels, and to train the next generations of engineering innovators in America with socially and professionally desirable qualities;
- The realistic expectations on the outcomes of K-12 engineering and technology programs, in terms of the limitations on expected academic and creative abilities of high school graduates from K-12 engineering and technology curriculum.

The proposed model has drawn references from the achievements of past and current programs across the United States, as well as the advice and advocacy of well-established scholars in the field (analogous to “gears” in a mechanical system, as shown in *Figure 16*); and reflects my understanding of what need to be done (analogous to “linkage and lubricant”). Hopefully, this model would contribute to the overall improvement of existing K-12 engineering and technology teacher education in the United States, in an idealistic yet realistic manner.

Prior research by Childress and Rhodes (2006, pp. 10-12) asked this interesting question: “What are the *engineering* student outcomes that prospective engineering students in grades 9-12 should know and be able to do prior to entry into a post-secondary engineering program?” and provided many generic and specific answers.

Smith and Wicklein (2007) further identified some essential aspects and related academic concepts of engineering appropriate for K-12 students.

Following the same path, the proposed model as explored in this paper intends to implement the general principles or guidelines presented in the research publications of the above well-established scholars, in terms of a new vision for K-12 Engineering and Technology Teacher Education, with specific course development and organizations.

Thus, some ground works have been completed. However, a lot of details still need to be investigated. Although this paper identified some K-12 appropriate engineering and technology courses that could be included in an engineering design-based curriculum, additional work needs to be done to determine what specific engineering analytic principles for each of these courses are most applicable in the context of the proposed model. For instance, pre-calculus and beginning calculus-based mechanism design could constitute a high school appropriate engineering course, but a list of specific topics still needs to be composed; and this could be done only by conducting a solid research, such as a 4-round Delphi study with experts in the field of engineering and technology, namely, university engineering and technology faculty, K-12 technology and STEM teachers and administrators, and practicing engineers and technicians.

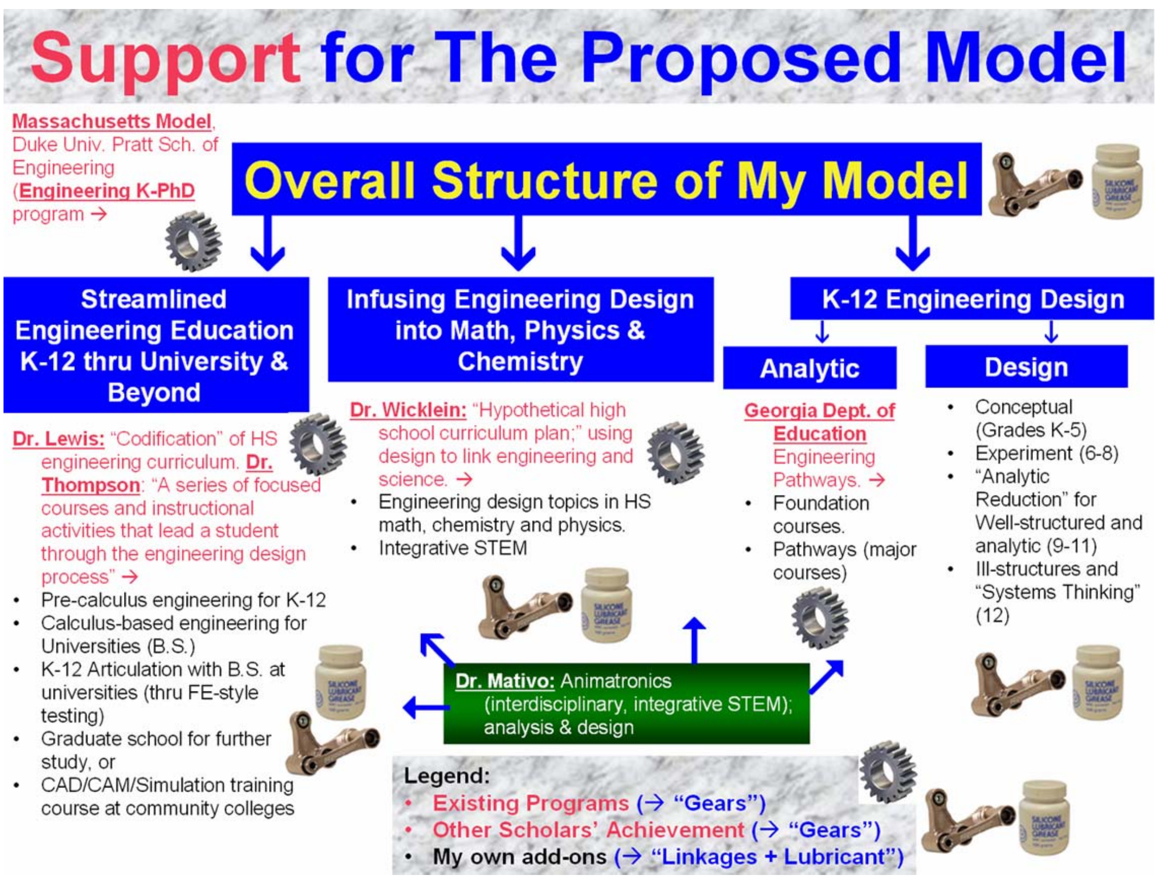


Figure 16. The way the proposed Model links past and current achievement with future possibilities.

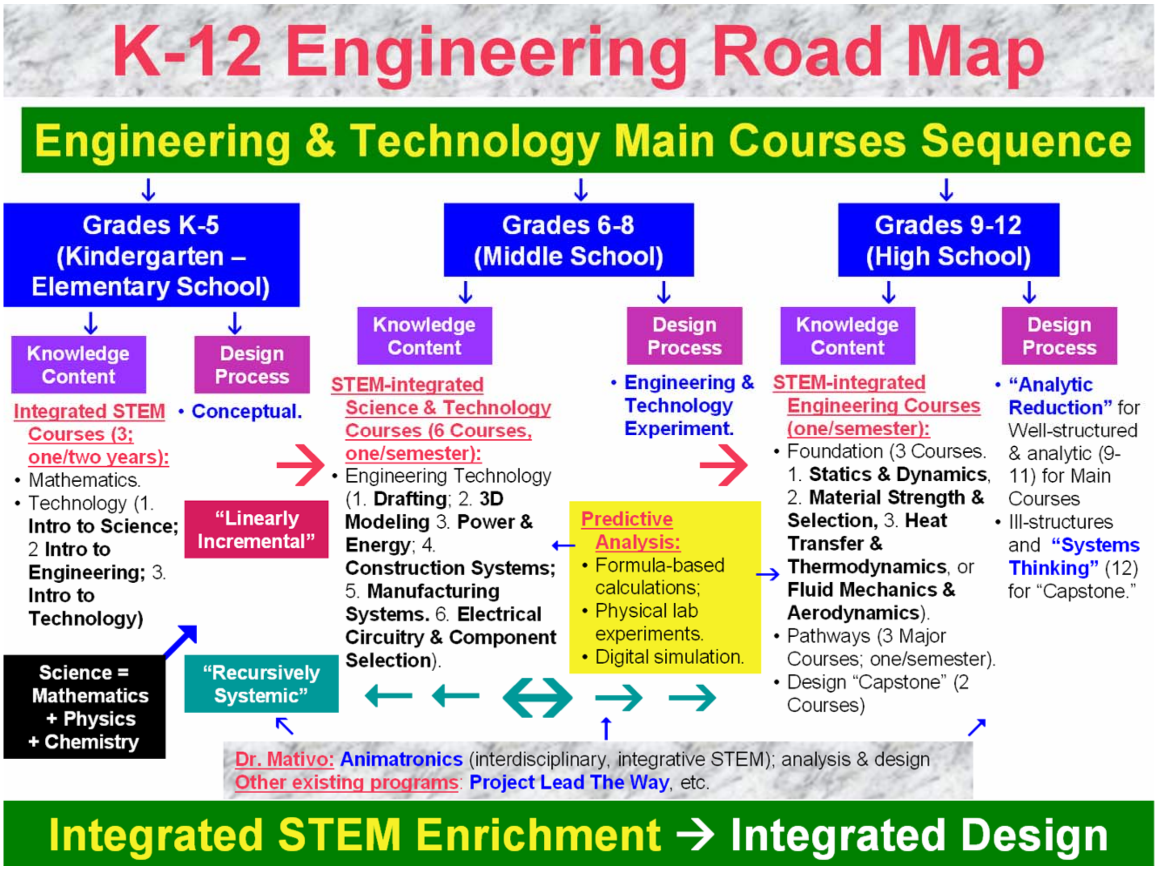


Figure 17. *Sequence of integrated K-12 engineering and technology courses with analytic and design course content.*

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