Appendix A:

Leadership White Paper:

Streamlining Engineering and Technology Education Across K-12 and University Spectrum:

A New National Direction

EOCS 9020 - Leadership Development in Workforce Education

Spring, 2008, College of Education, University of Georgia

Professor:

Robert Wicklein

Student:

Edward Locke (elocke@uga.edu)

Date of Submission:

Tuesday, April 30, 2008

Problem Abstract

The general objective of this White Paper corresponds to two of the research goals of the National Center for Engineering and Technology Education (NCETE): (1). "define the current status of engineering design experiences in engineering and technology education in grades 9-12;" (2). "identify guidelines for the development, implementation, and evaluation of engineering design in technology education" (NCETE, 2008).

The particular purposes of this Leadership White Paper are to:

1. Review the problem of critical shortage of engineering graduates from American schools and identify the emerging direction in engineering and technology education throughout K-12 and college-level: The emerging new direction might provide possible solutions to the critical shortage in the numbers of college graduates in engineering and technology majors, by increasing the numbers of American high school students interested in and well prepared for four-year undergraduate majors and engineering and technology, by strengthening math and science (physics and chemistry) education, and by integrating current career and technical education curriculum at high schools with four-year university programs.

2. Explore possibilities that might contribute to the solutions of the above-mentioned critical shortage under the new direction: This White Paper will focus on proposing potential improvement at local level (in the Athens areas surrounding the University of Georgia), but the ideas contained therein could be applied across the State of Georgia and in the entire United States, if appropriate experiments can be proved successful.

Critical Shortage of Engineering Graduates in the United States

Engineering and technology education is the backbone of America's economic growth. Since the end of World War II, the United States has played the role of global leader in engineering education and technological innovations; and for many decades, American universities graduated approximately 25% of all engineers in the world. However, in recent years, due to diverse factors, we are experiencing a critical shortage of graduates in engineering and technology programs, "Freshman enrollment in undergraduate engineering has hovered around 97,000 students each year since 2000," virtually unchanging in the years 2000-2005" (Iversen, 2005). Further details on this shortage are available in *Appendix A: Expanding Engineering Education in USA by Injecting Engineering Content into High School Technology and Pre-Engineering Curriculum*.

Leading Role of the National Science Foundation in the Emerging New Direction

According to a list compiled by Dr. Daniel L. Householder at the Utah State University Department of Engineering and Technology Education and others, the National Science Foundation (NSF) has funded in recent years many projects aiming at teacher training and instructional materials development for high school engineering and technology education (Householder et al, 2007).

1. K-12 engineering education teacher training and cross-institutional curricular articulation:

A. Bridges to Engineering Education: The primary focus of this project is "to design and develop a summer engineering education institute focusing on integration of engineering content with mathematics, science, and technology education that could motivate academically qualified high school seniors to seriously consider engineering majors in college." Under the leadership of Robert C. Wicklein, the Summer Engineering Institute took place on the campus of the University of Georgia, on June 2-13, 2003, with 46 students and faculty participants; and "culminated in the presentation and testing of student designed projects to solve an engineering related problem" (p. 18).

B. The Advancing Technological Literacy and Skills (ATLAS) model in Massachusetts: This project' goals include "strengthen elementary educators' knowledge of and capabilities to teach technology, engineering, and science" for K-12 students, and "develop articulation pathways related to elementary technology/engineering between high schools, community colleges, and four-year institutions. ATLAS partners include the Museum of Science in Boston, several community colleges, the University of Massachusetts at Amherst; several high schools; two industry partners; the Massachusetts Executive Office of Community Colleges; and three Tech Prep consortia (p. 2)

2. K-12 engineering education instructional materials development:

A. For primary school pupils:

(i). "How Things Work:" This project aims at introducing engineering concepts to primary students through creating educational resources for primary school teachers dealing with technical literacy and developing significant interactions between engineering programs and K-12 schools. The project initiators indicated that "unfortunately, many K-12 students lose interest and motivation for science, mathematics, and technology early in their school years. Consequently, technical programs and resources dealing with high school students and, to some extent, middle school students are too late in the educational process. Primary school instruction needs a strong technical component that captures the imagination and stimulates interest of students" (p. 17).

(ii). Engineering is Elementary: Engineering and Technology Lessons for Children: This project is aimed at "developing lessons to engage students in grades 1-5 in engineering activities integrated with their science lessons. The project addresses the need to develop a broad understanding of what engineers do and the uses and implications of the technologies they create. At the heart of engineering is an understanding of the engineering design process." The project is developing 20 units, each of which includes an illustrated storybook, teacher background materials, teachers guide, assessment tools, student duplication masters, quick cards, references, and resources, and a Website at www.mos.org/EIE (p. 46).

B. For secondary school students:

(iii). Technology Modules on the World Wide Web: This project created technology education modules for grades 9 to 12, accessible through the world-wide web at http://www.eng.buffalo.edu/shaw/ (safety light system, drying by design, and music in the digital world); the modules allow computer-assisted simulation, and are meant to supplement the more typical hands-on activities of technology teachers (p. 51).

(iv). Learning by Design: A Middle School Science Curriculum: This is "a project-based inquiry approach to middle school science. Students learn science content, scientific reasoning, and project skills in the context of achieving design challenges." The project created a Website at http://www.cc.gatech.edu/projects/lbd, which includes a series of modules for middle school science that engages students in studies of earth science and physical science, using complex realistic engineering design challenges, such as designing and building a working model of an erosion management system and making suggestions about tunnel locations and methodologies for digging; addressing force and motion and mechanical advantage, by designing and building a parachute, a miniature vehicle and its propulsion system that can go over several hills, and a machine to lift a heavy object (p. 52).

Local, Regional and National Efforts at Improving High School Education through Project-Based Engineering and Technology Curriculum or Systemic Curricular Path

The critical shortage in university level engineering and technology enrollment and graduation rate might be due to the following two major factors:

1. Inadequate quality of high school education in math, physics, and chemistry:

Due to many factors, which explanation is beyond the scope of this White paper but nevertheless can be found in many published research, quality of education in these critical areas at high school level have deteriorated in the last few decades; the recent national efforts at improving quality of high school math education since the No Child Left Behind has provided major impetus for improvement. Due to the fact that math, chemistry and physics courses taught at high schools constitute the foundation for a successful entry into engineering and technology major at university level, improvement in these vital areas should be continued. This might entail: (1). providing qualified teachers; (2). providing well-equipped and up-to-date technology (physical laboratory and digital technology, et.) to school districts, especially the impoverished ones where the needs are greater.

2. Building the bridge between high school career and technical education and university engineering and technology programs:

Traditionally, K-12 education has been considered as a local endeavor although State and Federal intervention, regulation and financial assistance have been made integral components of it. The decentralized structure in K-12 education surely allows citizens in local communities to tailor their educational endeavors to their practical needs; however, it also causes substantial degree of variations in terms of quality and inter-institutional disconnection. This is true for the preparation of high school students for university majors in engineering and technology. In recent decades, efforts have been made to remedy this problem:

A. Evolution of high school vocational or career education: Many high school vocational education programs have evolved into technology education, offering engineering content with design, problem-solving, and analytical skills to high school students.

B. Emergence and growth of innovative high school engineering programs: Many creative but practical engineering curricular models have been promoted at growing numbers of middle and high schools by national or regional non-profit organizations, with support from industry and government. They include:

(1). Project Lead the Way (PLTW): This organization's model, started in 1997, is among the most successful; in the State of Indiana alone, the number of high schools participating in PLTW pre-engineering program has grown from 159 schools in 2006 to 231 schools in 2007, a 45 percent increase (O'Hair et al, 2007). "Today, there are 1,700 PLTW schools in 46 states. […] Research shows that PLTW students are more likely to persist in engineering and related fields in college. As of 2005, 80 percent of graduates went on to college; of these, 68 percent majored in engineering" (Harris & Wakelyn, 2007). "Project Lead The Way offers three course-sequence options from grades 9 to 12. Over the four years, students choose from six 'engineering' courses (namely, Introduction to Engineering, Principles of Engineering, Digital Electronics, Digital Lab, Computer Integrated Manufacturing, and Engineering Design and Development). In each year they take an engineering course, along with Mathematics, Science, English, Social Studies, Physical education, and (except for grade 12) a foreign language. […] The middle school features a four-course sequence called Gateway to Technology, inclusive of Design and Modeling, The Magic of Electrons, The Science of Technology, and Automation and Robotics" (Lewis, 2004, pp. 24 - 25). According to the organization's web page titled Cutting-Edge for Today's Middle Schools at http://www.pltw.org/curriculum/hs-engineering.html, the above-mentioned and other courses offered by PLTW fall under three categories: (i). Foundation Courses (Introduction to Engineering Design, Principles of Engineering, Digital Electronics); (ii). Specialization Courses (Aerospace Engineering, Biotechnical Engineering, Civil Engineering and Architecture, Computer Integrated Manufacturing); and (iii). Capstone Course (Engineering Design and Development). The program offers College Credit for Students. "The National Affiliate/PLTW Exemplary Student Recognition program will provide an opportunity for students in a National Affiliate/PLTW certified school who have excelled in selected PLTW courses to receive transcripted, college credit for Principles of Engineering, Introduction to Engineering Design, Digital Electronics, and Computer Integrated Manufacturing."

(2). High School That Works (HSTW) Initiative: Managed by the Southern Regional Education Board, this model helps high schools integrate academic programs (math, reading, and technology) into career preparatory programs that have historically lacked rigorous academic standards, and vocational programs that prepare students for success in both postsecondary education and careers. "The number of *High Schools That Work* states has increased from 13 in 1987 to 32 in 2005, across the United States, including Georgia (Southern Regional Education Board, 2008).

(3). The "Stony Brook" model tested at Madison West High School: The name of the model "derived from the seminal work by Thomas T. Liao and his colleagues at the State University of New York at Stony Brook" (Lewis, 2004, pp. 24 - 25). Engineering and Materials Science program offered by the Technology Education Department, with support from SolidWorks 3D CAD developer, features many well-designed engineering courses that can be seamlessly integrated with those offered at university level. The program "features four-year course-sequence options (engineering or architecture). Both feature a common set of mathematics and science courses. Technical courses vary with focus. Engineering students take Materials Science, Design Drafting, and Engineering I, II and III." "Architectural students take Design/Drafting/CAD; Construction, Advanced Architecture, and Independent Study in Architecture (Madison West High School, 2008). The mathematics courses students take over the four years include Accelerated Geometry, pre-calculus, calculus I and calculus II. Science courses include biology, chemistry, and physics" (Lewis, 2004, pp. 24 - 25). Principles of Engineering I, II and III cover advanced topics such as Ergonomics, Management and Competition. Design/Drafting and Computer Aided Design courses feature cutting edge digital technology, including: a. 3D Animation using the 3D Studio MAX program that has many applications ranging from developing special effects to testing a prototype in a virtual environment; b. Mechanical Design using SolidWorks solid modeling program to see prototypes in a 3D virtual world; c. Architectural Design using the Architectural Desktop program to create project models in a digital environment; d. Graphic Design using the Adobe PhotoShop and Microsoft PowerPoint programs to manipulate images and text into a project or presentation (Imagine101.com, 2008). The model is very functional in integrating high school and college in engineering curriculum.

(4). DTEACH (Design Technology and Engineering for America's Children): This program is intended to infuse engineering design into the K-6 curriculum by introducing children to engineering concepts and devices (such as pulleys, levers and cams, and forms of energy), in an interdisciplinary approach. Students used their new knowledge to design and build models illustrating what they learned in other subjects. They worked in teams and engaged in a variety learning experiences in science and mathematics, and in technology. "One outstanding feature of DTEACH was the emphasis placed on identifying and codifying fundamental concepts and processes that students were expected to learn. The content identification scheme they reported is one of the more detailed that has appeared in the literature" (Crawford, Wood, Fowler, & Norrell, 1994; cited in Lewis, 2007, p. 846).

(5). Engineering Pathway: According to Dr. Lewis (2007, p. 850), this engineering-based curriculum project was led by Alice Agogino as Principal Investigator, and funded by the National Science Foundation (website: http://www.engineeringpathway.com/ep/); and it is "a major repository of resources for the teaching of engineering ideas K-12," which "provides a large number of curriculum units, spanning several domains of engineering, accompanied by lessons and hands-on activities;" the model is based on the assumption is that the teachers would not necessarily be engineers; and the lessons are designed in a down to earth manner (such as in "Animals and engineering"). The model also "provides a large array of engineering challenges that are connected to (science) standards (Lewis, 2007, p. 850).

(6). The City Technology: This is a program of the City College of New York Schools of Engineering and Education since around 1997 (Website: http://citytechnology.ccny.cuny.edu/), engaging 75 elementary teachers form Harlem and the South Bronx in developing strategies for basing science learning on designed, natural and human environments of New York City, with a focus on the designed environment, including artifacts, systems and environments designed by people. The program has conducted professional development sessions for several thousand teachers and informal educators in about 20 states. The program's workshops have taken place in many places including socio-economically disadvantaged communities such as Native American communities in Minnesota, Montana, Alaska; schools in rural Appalachia; and inner-city in New York, New Jersey, Washington, DC, Las Vegas, Los Angeles, and Jackson, MS. The program has conducted invited sessions at national meetings of professional organizations such as the National Academy of Engineering, American Society of Mechanical Engineers, and short courses at annual conventions of the National Council of Teachers of Mathematics and National Science Teachers Association (Benenson, 2007. p. 1). According to Dr. Benenson (pp. 736-737), this model uses two inductive processes as a first step in learning about an area of technology: (1). scavenger hunt (collecting physical objects from one's own life); and (2). brainstorming session (deriving creative ideas from experience or imagination). Another major step in the City Technology model of study of technology is based on the scientific inquiry process of selecting some representative examples and analyze them closely, raising questions such as: (a). What problems was it designed to solve? (b). What are the elements of the design that contribute to its functioning? (c). How well does it work in accomplishing its purposes?

Table 1. Overview of the Five City Technology Curriculum guides (Benenson, 2001. p. 734)

Title	Description	Major Concepts
Mapping (Benenson et al., 1999a)	Investigating how space is organized and used; creating maps to express meaning about space.	One-to-one correspondence, modeling, point of view, orientation, dimension, and scale.
Environmental Analysis & Design (Neujahr et al. 1999)	Examining the organization of space and time in daily life; designing and evaluating redesigns of classroom furniture, procedures, and storage space.	Problem identification; recognition of designed environments; design, redesign, and evaluation; social responsibility for environment.
Mechanisms, Circuits, and controls (Benenson et al. 1999b)	Analysis of simple mechanisms, e.g., nail clippers and folding chairs; design of cardboard model and linkages; identificatioin of control devices, such as switches and faucets; circuit design.	Inputs, outputs, cause-and-effect, systems; transmission of force and motion; information and control; modeling; feebdack.
Packaging and Structures (Benenson et al., 1999c)	Exploring how bags, boxes, cartons, and bottles are used to contains, protect, dispense, and display products; product testing of packaging; design and evaluation of useful classroom structures.	Structure, load and failure tradeoffs; compression, tension, and shear; material properties; recognition of possibilities for repair, redesign or reuse.
Signs, Symbols and Codes (Benenson et al., 2000)	Observing graphic devices found on packages, walls, and street signs; analysis of gestures and other signals; design and evaluation of symbols for school settings.	Information and communication; sign, symbol, signal, and code; source, receiver, and channel; visual, auditory, and tactile modes of transmission; redundancy.

The above models (PLTW, HSTW, City Technology, and the Madison High School or "Stone Brook" model) are quite beneficial in increasing high school student interests in university engineering and technology programs, although they are generally operated on a technology education model (using more "hands-on and "trial and error approach"), rather than on a strictly engineering design model (with a focus on analytical and predictive process based on the application of scientific principles and mathematical expressions or formulas).

(7). Regular Pre-engineering in Massachusetts or "Science and Technology/Engineering Framework:" Dr. Lewis evaluated this model as "a very promising approach to the introduction of engineering design in the schools […] which has gone further than any other state in the US in seeking to infuse engineering design into the curriculum, and in providing guidance in how to do so, […] deliberately connects science, technology and engineering in its curricular scheme, […] sets forth learning standards for the grade bands pre -2; 3-5; 6-8; and 9-12. […] address engineering elements directly in a way not ordinarily seen" (Lewis, 2007, p. 847). This model is "independent of the influence of any movement version of pre-engineering" such as PLTW and HSTW. The first striking aspect of how the subject is viewed in Massachusetts is that it is called "Technology/Engineering," showing a well-planned step-by-step "regular progression" from one field to another, in a rational, logical, systemic and methodic manner compatible to the gradual cognitive development of students, and to our general understanding of the incremental and sequential increase in problem-solving capability from mastery of declarative knowledge content to the solution of real-world problems through synthetic integration of diverse fields of knowledge content. "The State curriculum framework shows how science, engineering, and technology can intersect. It examines the unique natures of science and technology, as well as complementarities between them." This cross-subject intersection is explained by the authors of the program, i.e., engineering faculty from the School of Engineering at Tufts University, notably Ioannis Miaoulis, Peter Wong and Martha Cyr (Lewis, 2004, p. 32):

> Technology/Engineering works with science to expand our capacity to understand the world. For example, scientists and engineers apply scientific knowledge of light to develop lasers and fiber optic technologies and other technologies in medical imaging. […] In some of the most sophisticated efforts of scientists and engineers, the boundaries are so blurred that the designed device allows us to discern heretofore unnoticed patterns while accounting for those patterns makes it possible to continue to develop the device. In these instances, scientists and engineers are engaged together in extending knowledge.

"Throughout the grades, the curriculum guide takes an engineering slant" under the Massachusetts model:

- Grades 3-5: Students "learn about tools and materials, and are expected to display "engineering design skill" by finding and proposing solutions to problems, working with a variety of tools and materials." Simple and complex machines are covered during this grade band (Lewis, 2007, p. 847).

- Grades 6-8: Students "are expected to "pursue engineering questions and technological solutions that emphasize research and problem solving." Material identification, types of bridges and adaptive and assistive bioengineered products are covered during this grade band (Lewis, 2007, p. 847).

- Grades 9 and 10: Students “take a full year technology/engineering course covering engineering design; construction technologies; power and energy technologies in fluid, thermal and electrical systems; communication technologies; and manufacturing technologies.”

- Grades 11 and 12: Students “can take advanced courses such as automation and robotics, multimedia, and biotechnology. At this level there is a strong engineering careers focus, with course sequences available for students intending to pursue engineering programs at the college level.”

This Massachusetts “Science and Technology/Engineering Framework” is well designed by its advocates who are engineers themselves. In my opinion, this plan is worth considering as a start point for defining a new direction in American engineering education, the main point being not to start engineering and technology education after high school, but right from elementary years upward. In my humble opinion, this model, more systematically and effectively so than any other models, could help realize the democratic and progressive idea of “Technology for all Americans.” In addition to its apparent pedagogic benefits, “a pre-engineering approach that starts in pre-kindergarten is more likely to democratize the subject than one which starts later. It is quite possible that because of successes in technology education, some students, who ordinarily might be intimidated by high status subjects, would now venture to take such subjects;” thus, the plan offers great potential for “the children of the masses” to participate in engineering and technology careers (Lewis, 2004, p. 35).

3. Legislation to facilitate high school to college transition in engineering and technology pathways:

Past and current Nation-wide policies and initiatives at integrating secondary and postsecondary studies in career and technical areas include (Hughes & Karp, 2006, pp. 1 - 7):

(1). The College and Career Transitions Initiative (CCTI) and Career Pathway: This Initiative “focuses on career pathways as the main strategy for pursuing its goals.” A career pathway is “a coherent, articulated sequence of rigorous academic and career courses, commencing in the ninth grade and leading to an associate degree, an industry-recognized certificate or licensure, or a baccalaureate degree and beyond.[…] is developed, implemented, and maintained in partnership among secondary and postsecondary education, business, and employers. […] available to all students, including adult learners, and are designed to lead to rewarding careers.” In some places, different names such as Career Majors and Career Clusters might be used. “Aligning high school and college curricula across education sectors and career requirements is a hallmark of a career pathway.”

(2). Tech Prep: “Articulated Tech Prep sequences usually provide college credit for some portion of the high school course work, […] in the partnering college. […] it is estimated that the majority of community colleges in the country participate.”

(3) Dual enrollment: "Dual enrollment is emerging as a popular alternative to articulated courses. […] students take actual college courses, with credit recorded on a college transcript, eliminating the intermediate steps to credit earning required by many articulation arrangements. […] courses are first and foremost college courses, students may receive a more authentic college experience. […] Forty states have policies addressing dual enrollment. […] In some cases, dual enrollment students earn dual credit - high school as well as college credit."

Both pre-college technology curricula (Career Pathway and Tech Prep), and dual enrollment/credit are functional models for integrating engineering and technology education across high school and college levels.

4. Noticeable trend in the evolution of technology education in American high school in response to technological changes:

Traditional technology courses taught at high school include metal works, wood works that involved hands-on training on using manual and/or power-operated tools, for fabrication of custom-made projects or models. Due to technological changes, we nowadays have CNC prototyping equipment and other digitally-driven machineries used in industry. Thus, in some places, the relevance of traditional technology courses has decreased at various degrees. Responding to the new conditions in industry, the State of California "has all but eliminated industrial technology education" and is trying "to use pre-engineering as a new direction of bringing relevance and application to an otherwise academic only system." "California is focused around the more traditional standards of math, science, etc. than on career and technical areas;" and has developed Pre-Engineering standards for grades 9-12, with some schools featuring pre-engineering Career academies (e.g. in aerospace) (Lewis, 2004, pp. 26 - 28).

The Emerging New Direction to Facilitate and Accelerate Student Success in Engineering and Technology Education with Streamlining of Engineering and Technology Learning Process

The Massachusetts and other models explored in the last section could be identified as the emerging new direction in preparing K-12 students for engineering and technology programs at university level. The Massachusetts model could serve as the starting point for formulating general guidelines for K-12 engineering and technology education at national level, while other models could play important roles in the new national efforts.

To connect K-12 engineering and technology and/or CTE curriculum with university engineering and technology programs, promising models have emerged in recent decades:

1. Cross-Institutional articulation:

The ideas of cost-effectiveness, structural streamlining and lean manufacturing can be applied to engineering and technology education. With the continuous growth of digitally-driven new technology, students are expected to master a growing body of knowledge and skill content;

and all of these demand time, energy and financial resources. Therefore, we can ill afford any waste of time, energy and financial resources in engineering and technology education due to factors such as curricular duplication, institutional disconnection and others. We can be more cost-effective by streamlining the education process across all three levels of schooling (elementary, middle/high, and college/university) or three major institutions (K-12, two-year community colleges and four-year universities). The following two examples illustrate local, state and national efforts in this direction:

1. Bridging K-12 and two-year community colleges: In March 2007, California Governor Arnold Schwarzenegger hosted the state's first Career Technical Education Summit, which gathered education, business, labor, foundation, and political leaders to form strategies for CTE to help fill the need for qualified workers in fast-growing, high-demand fields." The proposed reforms of CTE instruction include: expanding the number of available courses and ensuring that classes are designed to prepare students for emerging growth industries; eliminating coursework duplication between high school and community college requirements (the new CTE programs strongly encourage students to attend a postsecondary institution by linking high school programs with those at the community college level. This linkage is logical, as states increasingly turn toward community colleges to generate a competitive workforce.); raising CTE's academic profile by increasing the number of high school courses that meet the course requirements for admission to California State Universities (Harris & Wakelyn, 2007, pp. 6 - 10).

2. Bridging two-year community colleges and four-year universities: Some two-year community colleges in southern California (in the greater Los Angeles area) have established "2 + 2 Articulation Agreements" with four-years public universities, which allow engineering and technology students to complete all of their lower-division undergraduate science foundation and engineering major courses, as well as most of general education courses, at community colleges and be certified when transferring to the later, and start right at the upper-division level upon transfer. These include: Pasadena City College and East Los Angeles College, each having 7 and 6 agreements with California State University at Los Angeles respectively, covering many majors in engineering and technology such as civil, electrical, general engineering technology, mechanical engineering or technology. For details, refer to p. 12 of *Appendix B: Overview of Engineering and CAD/CAM Technology Related Vocational Education at Community Colleges in Southern California: Ideas for Improving Engineering Curriculum at Santa Ana College.*

2. Cross-Institutional sharing of laboratory facilities:

In many places, institutions are sharing laboratory facility to save cost of investment. For example, Los Angeles Trade Technical College offers a course in strength of materials on its own campus but uses the laboratory facility in California State University at Los Angeles to conduct experiments.

3. Articulating high school engineering and technology course with two-year community colleges or four-year universities:

A. Establishment of nation-wide guidelines for high school engineering and technology curriculum:

(1). The International Technology Education Association's Center to Advance the Teaching of Technology and Science (ITEA-CATTS): This organization has developed a standards-based model for Grades K-12 for delivering technological literacy (Engineering byDesign™). ITEA has published a series of standard-based guideline books for implementing technological literacy throughout K-12 program, with standards and expectations for increasing student achievement in math, science, and technology (these guideline books are featured in the ITEA's website at http://www.iteaconnect.org/EbD/CATTS/cattspublicationsseries.htm); the stated goal of the organization includes "Restore America's status as the leader in innovation. Provide a program that constructs learning from a very early age and culminates in a capstone experience that leads students to become the next generation of technologists, innovators, designers, and engineers;" in establishing these guidelines, the organization has gone beyond the boundary of technology per see into the realm of ethical issues, stating that "Technology creates issues that change the way people live and interact. Technology impacts society and must be assessed to determine if it is good or bad" (ITEA, 2008). The application of these guidelines could fit seamlessly into existing requirements for students' learning at and graduation from high schools, making students feel attending traditional math and science courses more relevant to real world.

(2). The American Society for Engineering Education (ASEE): Within recent years, this organization has launched a large K-12 effort aimed at making engineering ideas more accessible to students. The website of this organization reveals the many fronts upon which it reaches out to schools (see http://www.asee.org/k12/index.cfm). According to Dr. Lewis (2007, p. 845), the organization created a guidebook as well as an newsletter designed for consumption in the schools. Some 350,000 teachers have received the guidebook, and the newsletter reaches 10,000 schools. There are six ASEE guidelines for improving engineering education in the schools: (a). hands-on learning; (b). interdisciplinarity; (c). connection with state mathematics and science standards; (d). efforts to attract the best teachers; (e). making engineering fun; and (f). fostering partnerships (especially between higher education and industry). Dr. Lewis gave credits to ASEE's efforts as "clearly noteworthy" for helping children to become more familiar with the work of engineers, and at the same time correctly pointed out that "more important, arguably, is the learning of engineering concepts and processes, and for this to occur, there would be need for curricular intervention," which includes: (1). Meeting "the practical challenges of curriculum change, including messy components such as the retraining of teachers;" and (2). Providing "curriculum materials that are of tested and proven quality."

B. Building a bridge between high school career and technical education and university engineering and technology education through articulation, personalized curricular adjustment based on problem-solving aptitude testing: Our mission as engineering and technology educators is to serve student needs the best we can; we all understand that engineering is a challenging and even intimidating subject for a lot of high school students. Adapting the servant model of leadership, we could consider streamlining the learning process for future generations of engineers, through the following:

(1). Launching students to engineering orbit in their early childhood: "General cognitive ability" or "fluid intelligence" (Northhouse, 2007, pp. 48-49) is "a person's intelligence" (perceptual processing, information processing, general reasoning skills, creative and divergent thinking capacities, and memory skills), which is "linked to biology" and "usually grows and expands up through early adulthood and then begins to decline with age." Engineering courses generally contain a lot of formulas worth memorizing. The earlier we introduce students to the field, the greater their chance to succeed. The previously mentioned Massachusetts model could be considered as a general framework for this new direction, while successful experience from other models (PLTW, HSTW, and Stone Brook) could be incorporated. The following timeline for benchmarking student success in engineering and technology programs, which constitute the essence of the new direction I consider as critically needed for a strategic solution to America's shortage in engineering graduates, could be proposed:

- At elementary school (Grades K -5): In addition to mastering arithmetic, English and other essential subjects of study, students could be introduced to a variety of subjects related to science, engineering and technology (basic concepts, simple formulas and practical applications); digital technologies (video show, games, and simple simulation software) could be used to apply the concept of "edutainment" so as to arouse student curiosity and increase their interests in these fields;

- At middle school (Grades 6-8): Focus should be placed on mastery of essential science-related subjects such as math, chemistry, and physics. Engineering and technology courses that require little math aptitude, such as introduction to engineering, computer-aided drafting, computer graphics, engineering ethics and appropriate use of science and technology, can be integrated into CTE programs at this level. Full credits for these courses should be articulated with colleges and universities through cross-institutional negotiations.

- At high school (Grades 9-12): Trigonometry-based portions of statics, dynamics, mechanism design, strength of materials could be taught to Advanced Placement students at this level. Instructional materials could be selected from the current college-level textbooks. The selection criteria should be: (1). math requirements for the topics (restricted to algebra, trigonometry and geometry) (2). real-world application (module-based). This additional curricular design can be integrated into existing high school engineering programs (such as PLTW, HSTW and Engineering by Design), as electives or Advanced Placement courses. Digital simulation projects could be incorporated into these courses, preparing students for greater success at college level. These courses could help high school students gain some degree of analytic and predictive abilities in engineering. In addition, a product design course could be considered, with reasonable expectation that high school students enrolled in engineering and technology paths could design consumer products involving simple mechanical devices with working drawings and 3D digital models (at schools with access to CNC prototyping equipment, working prototype-making could be included as part of expectation). Partial credits for these courses should be articulated with colleges and universities through cross-institutional negotiations.

The idea to introduce trigonometry-based statics, dynamics, mechanism design, strength of materials courses is based on some educated justifications. From my personal conversation with an engineering professor from Australia during the ITEA 2008 Convention in Salt Lake City, Utah, this has been done for a few years in Australia. Although further studies are needed, based on my understanding of high school age students' cognitive growth, this plan can work. The basic assumption underpinning this plan is that, for practical purpose, the mathematic requirements for large portions of most of the engineering knowledge content are pre-calculus (algebra including some portion of linear algebra, trigonometry and geometry) and beginning calculus (integration and differentiation). Dr. Karen Samuelsen at the College of Education, the University of Georgia, with a mechanical engineering background, advised me that for most part, practical mechanical engineers need more linear algebra than beginning calculus, in their design works. It can be reasonably believed that advanced high school students can handle this level of math, and succeed in high school level engineering courses, such as pre-calculus statics, dynamics, mechanism design, strength of materials. Introducing these engineering courses to high school students might help facilitate and accelerate students' transition to four-year university undergraduate engineering and technology programs.

<u>(2) Matching high school technology pathways with university engineering majors:</u> To systematically streamline engineering and technology learning process across the K-12 and university spectrum, the following Basic Engineering and Technology Pathways could be proposed for high schools:

<u>For Advanced Placement students with strong math performance (above B scores in trigonometry, geometry and algebra course):</u>

- Mechanical System and Manufacturing Engineering;
- Electrical/Electronics and Robotics Engineering;
- Computer Science and Engineering;
- Civil engineering;
- Biological and Agricultural Engineering.

<u>For students with above average math performance (above B- scores in trigonometry, geometry and algebra course):</u>

- Product Design Engineering;
- Construction Technology and Architectural Design.

The above Basic Engineering and Technology Pathways could prepare high school students to any corresponding college or university undergraduate engineering programs across the United States. In addition, depending on local conditions, such as proximity to large corporations or research facilities, or universities offering specialized engineering programs, Specialized Engineering and Technology Pathways could be considered for:

- Aerospace Engineering and Technology;
- Genetic Engineering and Technology;
- Agricultural Engineering and Technology, etc..

My Potential Contribution to National Endeavors at Strengthening Engineering and Technology Capacity in the Emerging New Direction

The emerging new direction in American high school engineering and technology education has been identified in the last section of this White Paper. There is no need for this White Paper to formulate any other direction. Aligning my personal dream with American people's dream, my role is one of a team member, appreciating the previous achievement of others, while trying to find an opportunity to contribute, not as a lone soldier, but as a servant-style member of the leadership team, thinking nationally but working locally.

1. Advice from well-known scholars: Strengthening analytic and predictive abilities through enlarging content knowledge base:

Lewis (2005, p. 50) identified "two scenarios that arise on the question of the importance of domain knowledge" in high school engineering and technology education, "each approach has an important and peculiar purpose:"

- To teach just the generic process of design: "It is conceivable that the teacher could proceed without consideration of domain knowledge. He/she could rely upon commonplaces (every-day materials or artifacts) about which the functional knowledge of students is assured, and could teach in a domain-independent manner."
- To facilitate the solution of a design challenge within a particular domain: "Students will need some degree of requisite pre-knowledge, depending upon the domain, whether electronics, materials, or construction."

Dr. Scott Johnson pointed out that currently, engineering and technology courses at high school are using a "trial-and-error" type of technology design approach rather than typical analytic and predictive engineering design approach (lecture, HRE 510 course, UIUC, Spring 2008). Dr. Theodore Lewis (2005, p. 50) criticized the current practice of judging high school student performance by identifying the winner of a particular competition alone (longest bridge, or structure able to bear the most weight), through a "rote approach to design," which misrepresents and grossly oversimplifies the task of the engineer, and […] inhibits student creative performance, a critical aspect of which is the possession of requisite content knowledge;' and then asked this critical question: "How much domain knowledge should technology students possess before it is assumed that they can competently tackle design problems? This question has to be given greater consideration now, because of links to engineering." Dr. Robert Wicklein proposes infusing engineering design into the technology education curriculum more deliberately, outlining broad categories for the infusion of engineering design into technology education, which includes, "…narrative descriptions, graphical explanations, analytical calculations, physical creation;" he includes as essential in the curriculum optimization, analysis, and prediction (Wicklein, 2006, pp. 6 - 7*)*.

2. My perception of the most important critical agenda item that requires significant leadership on my part as a servant-style team member:

The previous section of this White Paper has proposed some audacious but realizable plan of bringing portions of college-level engineering and technology content knowledge into high school classroom, and of articulating them with college-level lower-division engineering courses, so as to streamline and accelerate student success in engineering and technology major. My contribution to this broad effort is limited to developing instructional materials and conducting pilot teaching and learning experiments for the proposed pathways of Mechanical System and Manufacturing Engineering and Product Design Manufacturing, in Athens-Clarke County School District, around the University of Georgia. I believe that this is the most important critical agenda item that requires significant leadership on my part, which is within my capabilities.

A. Developing instructional materials: Based on literature review from the Journal of Technology Education, on advice from experts, and on studies of available models (PLTW, HSTW, and others), I have tentatively concluded that we need more efforts at designing innovative courses that offer "requisite pre-knowledge" in basic engineering to high school student and "facilitate the solution of a design challenge within a particular domain." These new courses can include, for the proposed pathways of Mechanical System and Manufacturing Engineering and Product Design Manufacturing, the following that combine pre-calculus (geometry, trigonometry and algebra) based analytic and predictive knowledge content, physics laboratory experiment, and digital simulation, in modular units, which are suitable to the cognitive developmental level of high school students:

- Statics: The focus of this course is on resultant of forces in a plane and in space, resultant of forces and resolution of a force, Newton's 1st law, graphical force addition in 2D and 3D with AutoCAD, free body diagram, equivalent system of forces, and equilibrium of rigid bodies. Pre-requisite: high school algebra and trigonometry. Partial credit can be articulated with college-level statics course.

- Dynamics: Basic rules of differentiation and integration will be taught or reviewed first. The focus of this course is on the coordinate systems (rectangular, normal and tangential, and polar), rectilinear motion, plane and space curvilinear motion, Newton's 2nd law, work and energy, impulse and momentum, and impact. Pre-requisite: high school statics. Partial credit can be articulated with college-level dynamics course.

- Strength of Materials: The focus of this course is on basic concepts of stress, strain, stress-strain diagram, and Modulus of elasticity, and related laboratory experiment and digital simulation. Pre-requisite: high school statics. Partial credit will be articulated with the laboratory portion of college-level strength of material course.

- Engineering Materials and Selection: The focus of this course is on the properties, applications, and process of production of engineering materials (metal, plastics, ceramic, fibers, polymers, etc.), location and selection of materials from Internet and other sources. Pre-requisite: high school chemistry. Partial credit can be articulated with college-level engineering materials course.

- Mechanical Devices Design and Selection: The focus of this course is on the applications of simple mechanical devices (shafts, screws and fasteners, welding and joints, mechanical spring, gears, cams, bearings, linkages, motors, and others), and selection of out-of-shelf stock items from Internet and library research. Pre-requisite: high school statics. No credit will be articulated with college-level mechanical design course; however, students will be exposed to a variety of important topics.

I will first submit this White Paper to Dr. Robert Wicklein (my major Professor), Dr. Roger Hill (in charge of my Ph.D Program), Dr. John Mativo (Engineering Professor and expert on mechatronics or robotics), Dr. Sidney Thompson (UGA Engineering Undergraduate Program Coordinator), Dr. Williams Kassaalita (UGA Graduate Engineering Program Coordinator), the leaders of NCETE and ITEA, as well leaders of Athens-Clarke County School District, to solicit their valuable advice and support, and upon approval, formulate detailed plans for the development of these instructional materials; I will participate and recruit volunteers from graduate engineering students at Driftmier Engineering Center and form a team to work on the project.

B. Pilot pedagogic experiment: Upon the completion of some instructional materials, pilot teaching experiments could be conducted at local high schools, within the Athens-Clarke County School District; and authentic assessment mechanism could be designed to evaluate the results of the experiment. To ensure the validity of teaching experiment designs, I shall request for advice on statistics from Dr. Carl Huberty and Dr. Karen Samuelsen, both experts in the field of educational research designs and Professors at the College of Education, University of Georgia. For details on a tentative plan written for similar experiment, see *Appendix C - Proposed Program: Engineering Design Technology Program for Career Academy at Clarke Central High School*. This pilot teaching experiment could be conducted by UGA graduate engineering and technology students including myself, once the Institutional Research Board grants approval. The results would be submitted to NCETE and ITEA for evaluation and potential publication.

4. The leadership needed to cause it to happen or bring it to scale:

Three levels of leadership are needed in the national endeavors of bridging the gap between high school and university engineering and technology education, as previously explored in this White Paper:

A. National leadership (upper level): Leaders of NCETE and ITEA, such as Dr. Kurt Becker at Utah State University, and others; they could provide visionary advice in terms of general direction to pursue;

B. Local leadership (middle level): Leaders of College of Education and Driftmier Engineering Center at the University of Georgia, such as Dr. Robert Wicklein, Dr. John Mativo, Dr. Roger Hill, Dr. Sidney Thompson, and Dr. Williams Kassaalita, as well as leaders of Athens-Clarke County School District; they could provide visionary advice in terms of general direction to pursue, and professional advice in terms of project feasibility, as well as logistics support;

C. Grass-root level (lower level): Myself, and volunteers among graduate students from he University of Georgia. The team will work on details of the project. Collective team leadership approach should be employed.

5. The detail plan that would be needed to underpin development of the initiative explore in this White Paper: Two sets of detailed plans are needed:

A. Instructional Materials Development Plans: These include textbooks appropriate for high school students, PowerPoint presentation files, teaching plans, learning activity sheets, concept and formula sheets, physical models, and others;

B. Teaching Experiment Plans: These include outlines for the experiment, plan of evaluation for student performance, plan for teacher evaluation, application for Institutional Research Board (IRB) approval, research plan, and others. The post-experiment research paper might aim at answering some questions related to the following three major topics:

1. To what extent would it be adequate to prepare high school students for a college engineering curriculum, to be more specific, what are the appropriate subject matters or topics from traditional college-level engineering courses that can be injected into high school technology curriculum, based on high school students' cognitive maturity level?

2. What can be an ideal outcome for high school students enrolled in engineering technology education upon completion of the program? In other words, in the following engineering-related areas, at what level can we expect high school students enrolled in engineering and technology programs to achieve: (1) math and science foundation; (2) engineering design and (3) drafting?

3. In what areas should improvement on pedagogy in high school engineering technology classroom occur, in terms of teacher training, usage of modern instructional technology, and others?

Conclusion

This White Paper has:

- Identified the emerging national direction in high school engineering and technology education in terms of its relevance to university engineering programs;
- Defined the role engineering faculty and students at the University of Georgia could play in the national endeavors at improving high school engineering and technology education;
- Indicated the detail plans needed to underpin the development of the initiative explored in this White Paper, which are to be worked out afterwards, upon approval from leaders at NCETE and UGA.

Reference

Benenson, G. (2001). The Unrealized Potential of Everyday Technology as a Context for Learning. *Journal of Research in Science Teaching*, Vol. 38, No. 7, pp. 730-745

Bauman, K. J., & Graf, N. L. (2008). *US Census Bureau Census 2000 Brief: Educational Attainment: 2000*. Issued August 2003 (C2KBR-24). p. 5. From http://www.census.gov/population/www/cen2000/briefs.html

Bishaw, A. & Iceland, J. (2008). *U.S. Census Bureau Census 2000 Brief: Poverty 1999, Issued May, 2003 (C2KBR-19)*, p. 8. From http://www.census.gov/population/www/cen2000/briefs.html

Bottoms, G. & Anthony, K. (2007). *Project Lead the Way: A Pre-Engineering Curriculum That Works, A New Design for High School Career/Technical Studies*. From Southern Regional Education Board website at http://www.sreb.org/programs/hstw/publications/briefs/ProjectLeadTheWay.asp

Brand. C. (2007). *EU Unveils Plans for "Blue Card" Program.* The MoscowTimes.com. Extracted Wednesday, October 24, 2007 from http://www.themoscowtimes.com/stories/2007/10/24/252.html

Brand C. (2007). *EU unveils plan to court skilled workers.* Associated Press. From http://www.journalgazette.net/apps/pbcs.dll/article?AID=/20071029/BIZ/710290337

Broache, A. (2007). *U.S. firms fear Europe will snatch up foreign tech workers.* Extracted October 25, 2007 from http://www.news.com/8300-10784_3-7-0.html?keyword=immigration

Chamberlain, Craig (2004). Illinois part of new center bringing engineering into high schools. Urbana-Champaign: News Bureau, UIUC. Extracted from http://www.news.uiuc.edu/NEWS/04/0913edtech.html

Crotty, M. (1998). The foundations of social research: Meaning and perspective in the research process. Thousand Oaks, CA: Sage.

Drukier, Cindy & Jekielek, Jan (2005). Training of American Engineers Must Change, Experts Say. Extracted November 23, 2005 from http://en.epochtimes.com/news/5-11-23/34912.html

EDSN (2005). U.S., Indian Universities Team to Improve Engineering Education. Extracted from http://www.edn.com/article/CA628212.html

Edley, C. (2004). *Losing our future: How minority youth are being left behind by the graduation rate crises*. Cambridge, MA: Civil Rights Project at Havard University.

Engardio, P (2005). Engineering: Is the U.S. Really Falling? Extracted from http://www.businessweek.com/bwdaily/dnflash/dec2005/nf20051223_7594_db039.htm

Gollnick, D. M., & Chinn, P. C. (2006). *Multicultural Education in a Pluralistic Society, 7th Edition*. Upper Saddle River, NJ: Prentice Hall.

Harris, A., & Wakelyn, D. (2007). Retooling Career Technical Education. From the website of Career & Technical Education National Research Center at http://www.nccte.org/Research/RecentResearch1.html

Householder, D. L. et al. (2007). *Selected NSF Projects of Interest to K-12 Engineering and Technology Education (NSF Projects in ETE).* From http://ncete.org/flash/resources.php

Hughes, K. L., & Karp, M. M. (2006). *Strengthening Transitions by Encouraging Career Pathways: A Look at State Policies and Practices.* From http://www.aacc.nche.edu/Template.cfm?Section=Headlines&Template=/ContentManagement/ContentDisplay.cfm&ContentID=15896

Imagine101.com. (2008). *Madison West High School Engineering*. From http://www.imagine101.com/course%20descriptions.html

International Technology Education Association (ITEA). (2008). *Engineering byDesign™ Center to Advance the Teaching of Technology & Science (CATTS) Professional*

Publications Series. From http://www.iteaconnect.org/EbD/CATTS/cattspublicationsseries.htm

Iversen E. (2004). *Leading Educators Propose Solution to Engineering Deficit.* From http://www.engineeringk12.org/about/Media_Center/default.php

Iversen E. (2005). *ASEE Announces New User Interface for K12 Outreach Program Database.* From http://www.engineeringk12.org/about/Media_Center/default.php

Lather, P. (2004). *Critical Inquiry in Qualitative research: Feminist and Poststructural Perspectives: Science "After truth." Foundations for Research Methods of Inquiry in Education and the Social Sciences).* London: Lawrence Erlbaum Associates, Publishers

Lewis, T. (2004). *A Turn to Engineering: The Continuing Struggle of Technology Education for Legitimization as a School Subject*. Journal of Technology Education: vol 16, No. 1, Fall 2004. From http://scholar.lib.vt.edu/ejournals/JTE/v16n1/pdf/index.html

Lewis, T. (2005). *Coming to Terms with Engineering Design as Content*. Journal of Technology Education: vol 16, No. 2, Spring 2005. From http://scholar.lib.vt.edu/ejournals/JTE/v16n2/pdf/index.html

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

Madison West High School. (2008). *Madison West High School Engineering*. From http://www.imagine101.com/course%20descriptions.html

Marshall, C., & Rossman, G. B. (2006). Designing Qualitative Research, 4th Ed. London: Sage Publications.

Mativo, J. & Rouch, D. & Miller A. & Bland A. (2006). *Perceptions of Ohio Engineers on the Role of Technology Education in their Preparation for a Career in Engineering.* PowerPoint lecture presented at ITEA (International Technology Education Association), Baltimore, March 22-26, and given to Edward Locke

Morris, W. (1981). *The American Heritage Dictionary of the English Language*. Boston: Houghton Mifflin Company.

NCETE (2008). *Research* goals. From http://ncete.org/flash/research.php

Northhouse, P. G. (2007). *Leadership theory and practice, 4th Edition*. Thousand Oaks: CA: Sage Publications, Inc.

Office of the Secretary of the United States Department of Health, Education, and Welfare. (1979). Ethical Principles and Guidelines for the Protection of Human Subjects of Research. From http://www.hhs.gov/ohrp/humansubjects/guidance/belmont.htm

O'Hair, M., Schulz, T. & Shutt, P (2007). *Collaboration Key to Making Indiana PLTW First in Nation*. From http://www.pltw.org/in-the-news/in-the-news.html

Project Lead The Way (2007). *Forging new generations of engineers*. From http://www.pltw.org/presentations-center.html (PLTW PowerPoint Download site)

Social Science Data Analysis Network (SSDAN), CensusScope. (2008). *Population by Race: Hispanic Population and Race Distribution for Non-Hispanic Population*. From http://www.censusscope.org/us/chart_race.html

Southern Regional Education Board. (2008). *Becoming a High Schools That Work State or Site*. From http://www.sreb.org/programs/hstw/becoming/becomingindex.asp

Steyn. M. (2006). *America Alone: The End of the World as We Know It.* Washington, DC: Regnery Publishing, Inc.

Swanson, C. B. (2004). *Who graduates? Who doesn't? A statistical portrait of high school graduation, class of 2001*. Washington, DC: Urban Institute.

US Department of Education Institute of Education Statistics National Center for Education Statistics. (2007). *The Nation's Report Card: Mathematics 2007*. From http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2007494

U. S. Department of Labor. (2004). *State Occupational Projections (Long-term, 2004 – 2014)*. From http://www.projectionscentral.com/projections.asp?page=DisplayResults&occ=Mechanical%2520Engineers&sortby=title&area=All&rsPage=1

The Nation's Report Card (2008). *District Mathematics Results by Race/Ethnicity*. From http://nationsreportcard.gov/tuda_reading_mathematics_2005/t0019.asp?subtab_id=Tab_2&tab_id=tab2&printver=#chart

Wicklein, R. C. (2006). Five good reasons for engineering design as the focus for technology education. *The Technology Teacher*, (65)7, 25-29.