Texas Higher Education Coordinating Board

Making Opportunity Affordable in Texas:

A Student-Centered Approach

Tuning of Civil Engineering

Texas Higher Education Coordinating Board

Austin, Texas

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Tuning Oversight Council for Engineering

Civil Engineering Committee

Kenneth A. Rainwater, Ph.D. (Chair) ***Committee Chair*** Professor, Civil Engineering Director, TTU Water Resources Center Texas Tech University Lubbock, Texas ken.rainwater@ttu.edu	**Jess T. Dowdy, Ph.D. (Co-Chair)** Professor of Physics and Chemistry Northeast Texas Community College Mount Pleasant, Texas
Robin L. Autenrieth, Ph.D. Associate Dean Graduate Programs in Civil Engineering Texas A&M University College Station, Texas	**Frank Lewis** Academic Division Director Texas State Technical College-Harlingen Harlingen, Texas frank.lewis@harlingen.tstc.edu
Tom Papagiannakis, Ph.D. R.F. McDermott Professor and Chair Civil Engineering The University of Texas at San Antonio San Antonio, Texas at.papagiannakis@utsa.edu	**Judy A. Perkins, Ph.D.** Professor, Civil and Environmental Engineering Prairie View A&M University Prairie View, Texas juperkins@pvamu.edu
Thomas Pressly, Ph.D. Engineering Faculty and Discipline Coordinator Alamo Community College District Northwest Vista College San Antonio, Texas tpressly@alamo.edu	**Vivek Tandon, Ph.D.** Associate Professor, Department of Civil Engineering The University of Texas at El Paso El Paso, Texas vivek@utep.edu
Robert L. Yuan, Ph.D. Chair, Department of Civil Engineering Lamar University Beaumont, Texas robert.yuan@lamar.edu	**Nicholas Vasquez (Student Representative)** The University of Texas at San Antonio San Antonio, Texas nick1shot@yahoo.com
Reinold Cornelius, Ph.D. THECB Staff Liaison Program Director Academic Affairs and Research Texas Higher Education Coordinating Board Austin, Texas	

Table of Contents

Definition of Tuning

"Tuning" is a faculty-led pilot project designed to define what students must know, understand, and be able to demonstrate after completing a degree in a specific field, and to provide an indication of the knowledge, skills, and abilities students should achieve prior to graduation at different levels along the educational pipeline – in other words, a body of knowledge and skills for an academic discipline in terms of outcomes and levels of achievement of its graduates.

Tuning provides an expected level of competency achievement at each step along the process of becoming a professional: expectations at the beginning of pre-professional study, at the beginning of professional study, and at the transition to practice. It involves seeking input from students, recent graduates, and employers to establish criterion-referenced learning outcomes and competencies by degree level and subject area. Through Tuning, students have a clear "picture" of what is expected and can efficiently plan their educational experience to achieve those expectations. The objective is not to standardize programs offered by different institutions but to better establish the quality and relevance of degrees in various academic disciplines.

An overview of Lumina Foundation for Education's "Tuning USA" Initiative is available at: http://www.luminafoundation.org/our_work/tuning/; an overview of Tuning work to date in Texas is available at: http://www.thecb.state.tx.us/tuningtexas.

Definition of Civil Engineering

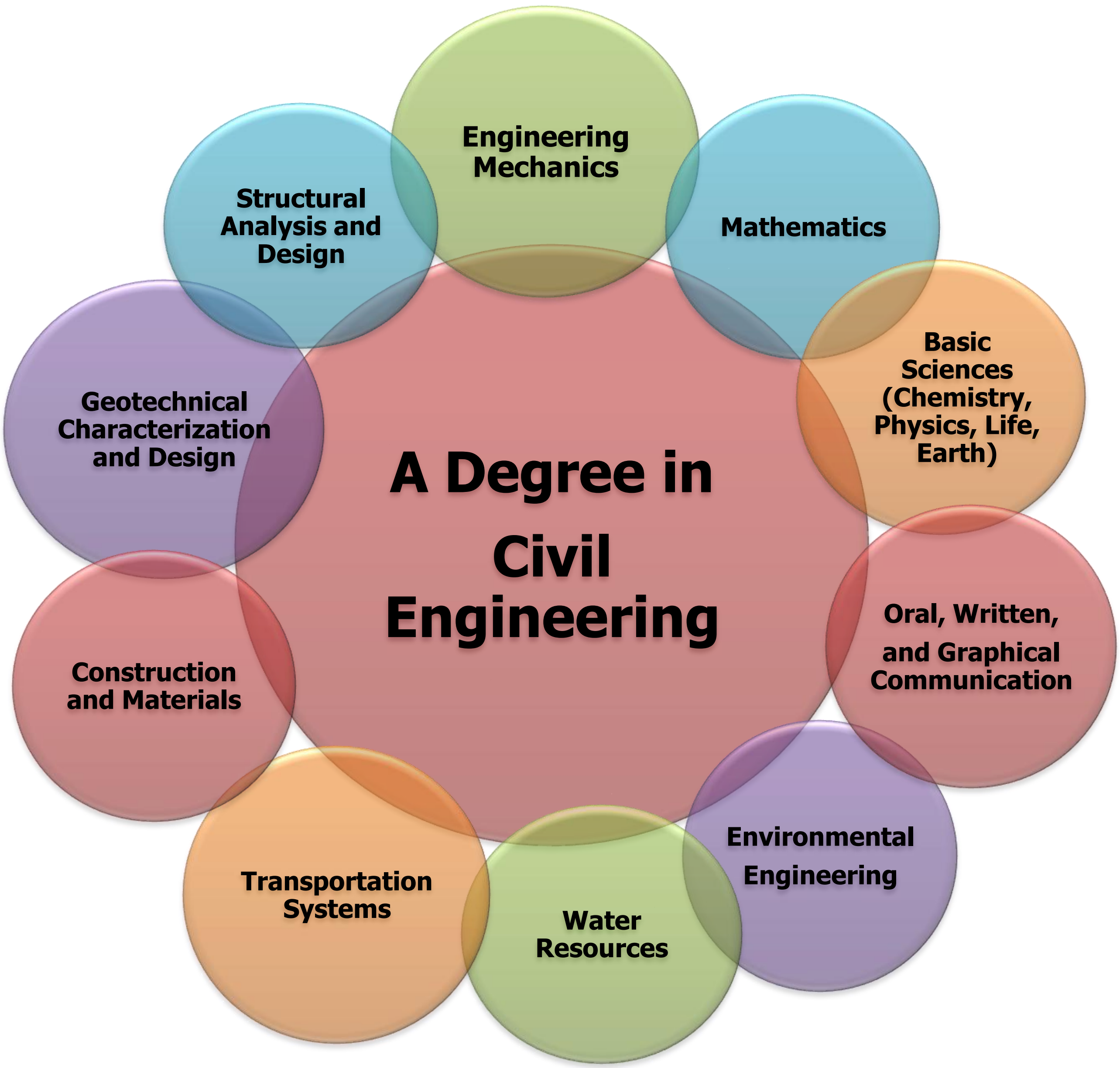
Civil engineers are entrusted by society to create a sustainable world and enhance the global quality of life. Civil engineers serve competently, collaboratively, and ethically as:

- planners, designers, constructors, and operators of society's economic and social engine, the built environment;
- stewards of the natural environment and its resources;
- innovators and integrators of ideas and technology across the public, private, and academic sectors;
- managers of risk and uncertainty caused by natural events, accidents, and other threats; and,
- leaders in discussions and decisions shaping public environmental and infrastructure policy.

After the American Society of Civil Engineers (ASCE) 2025 vision for Civil Engineering.

Civil Engineering Expertise Profile

The expertise profile lists types of course topics included in typical baccalaureate degrees in civil engineering. Note: general undergraduate degree requirements (e.g., the core curriculum) are not considered for the purpose of tuning civil engineering and this report.



Civil Engineering Employment Profile

The employment profile lists the employment pathways available for graduates of civil engineering programs.

ASCE has a description of Civil Engineering career paths that may help students to fit their professional development with their goals and interests:
http://www.asce.org/uploadedFiles/Leadership_Training_-_New/careerpathfinal.pdf

Civil Engineering Key Competencies Profile

The key competencies profile is a schematic diagram that is derived from the competency table. It lists for each learning outcome (columns) the required competency levels according to Bloom's taxonomy (rows) that have to be gained at each of four educational levels:

1. secondary education competencies, marked "HS"
2. pre-engineering competencies, marked "CC"
3. baccalaureate-level competencies, marked "BS"
4. graduate-level competencies, marked "G"

The level of response for each of the Bloom's taxonomy levels is described through active verbs; examples of verbs for each level can be found at:

<http://www.teach-nology.com/worksheets/time_savers/bloom/>

Civil Engineering Key Competencies Diagram

Lumina Foundation Grant Civil Engineering Committee

Evaluation				G	G	G				G	G
Synthesis				G	G	BS		G	G	G	G
Analysis	G	G	G	BS	BS	BS	G	G	BS	BS	G
Application	BS	BS	BS	BS	BS	BS	BS	BS	BS	CC	BS
Comprehension	CC	CC	CC	CC	CC	BS	CC	CC	BS	HS	CC
Knowledge	HS	HS	HS	CC	HS	CC	HS	HS	CC	HS	HS
	Mathematics	Natural Sciences	Materials Science	Mechanics	Experiments	Design	Teamwork	Problem Recognition and Solving	Ethics	Communication	Contemporary Issues and Historical Perspectives

G	**graduate-level experience competencies**
BS	**baccalaureate-level competencies**
CC	**pre-engineering competencies**
HS	**high school graduate competencies**

Civil Engineering Key Competency Tables and Learning Outcome Descriptions

The Civil Engineering competency table has eleven learning outcome titles, one for each learning outcome description:

1. Mathematics
2. Natural Sciences
3. Materials Science
4. Mechanics
5. Experiments
6. Design
7. Teamwork
8. Problem Recognition and Solving
9. Ethics
10. Communication
11. Contemporary Issues and Historical Perspectives

The competency table has four learning outcome categories (columns from left to right):

1. core competencies needed to enter higher education in civil engineering (HS),
2. pre-engineering competencies gained during first two years of study (CC),
3. baccalaureate-level engineering competencies (BS), and,
4. graduate-level engineering competencies (G)

Learning outcome descriptions for each of the outcome titles of the competency table explain the knowledge, skills, and attitudes that should be achieved by the graduates.

Mathematics

Mathematics deals with the science of structure, order, and relation that has evolved from counting, measuring, and describing the shapes of objects. It uses logical reasoning and quantitative calculation, and is considered the underlying language of science. The principal branches of mathematics relevant to civil engineering are algebra, analysis, arithmetic, geometry, calculus, numerical analysis, optimization, probability, set theory, statistics, and trigonometry.

The civil engineering graduate solves problems in mathematics through differential equations and *applies* this knowledge to the solution of engineering problems. The mathematics required for civil engineering practice must be learned at the undergraduate level and should prepare students for subsequent courses in engineering.

MATHEMATICS			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
Solve problems in mathematics in algebra, plane geometry, trigonometry, and analytical geometry (or pre-calculus), and apply this knowledge to the solution of science and technology problems. Students should be ready to complete calculus I in their first college semester	Explain key concepts and problem-solving processes in mathematics through differential equations	Solve problems in mathematics through differential equations and apply this knowledge to the solution of engineering problems	Analyze a complex problem to determine the relevant mathematical principles and then apply that knowledge to solve the problem

Natural Sciences

Underlying the professional role of the civil engineer as the master integrator and technical leader is a firm foundation in the natural sciences. Physics and chemistry are two disciplines of the natural sciences that have historically served as basic foundations. Additional disciplines of natural science are also assuming stronger roles within civil engineering.

Physics is concerned with understanding the structure of the natural world and explaining natural phenomena in a fundamental way in terms of elementary principles and laws. Mechanics is concerned with the equilibrium and motion of particles or bodies under the action of given forces. Many areas of civil engineering rely on physics for understanding the underlying governing principles and for obtaining solutions to problems.

Chemistry is the science that deals with the properties, composition, and structure of substances (elements and compounds), the reactions and transformations they undergo, and the energy released or absorbed during those processes. Chemistry is concerned with atoms as building blocks, everything in the material world, and all living things. Some areas of civil engineering—especially environmental engineering and construction materials— rely on chemistry for explaining phenomena and obtaining solutions to problems. Additional breadth in such natural science disciplines as biology, ecology, geology, and geomorphology will eventually be required to prepare the civil engineer of the future. Civil engineers should have the basic scientific literacy that will enable them to be conversant with technical issues pertaining to environmental systems, public health and safety, durability of construction materials, and other such subjects.

The civil engineering graduate solves problems in calculus-based physics, chemistry, and one additional area of natural science and *applies* this knowledge to the solution of engineering problems. The physics, chemistry, and breadth in natural sciences required for civil engineering practice must be learned at the undergraduate level and should prepare students for subsequent courses in engineering and engineering practice.

NATURAL SCIENCES			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
Explain key concepts in physics, chemistry, and biology and solve related problems	Explain key concepts and problem-solving processes in chemistry, calculus-based physics, and one additional area of natural science	Solve problems in calculus-based physics, chemistry, and one additional area of natural science and apply this knowledge to the solution of engineering problems	Analyze complex problems to determine the relevant physics, chemistry, and/or other areas of natural science principles and then apply that knowledge to solve the problem

Table of Contents

Materials Science

Civil engineering includes elements of materials science. Construction materials with broad applications in civil engineering include ceramics like Portland cement concrete and hot mix asphalt concrete, metals like steel and aluminum, as well as polymers and fibers. An understanding of materials science also is required for the treatment of hazardous wastes utilizing membranes and filtration. Infrastructure often requires repair, rehabilitation, or replacement due to degradation of materials.

The civil engineer is responsible for specifying appropriate materials. The civil engineer should have knowledge of how materials systems interact with the environment so that durable materials that can withstand aggressive environments can be specified as needed. This includes the understanding of materials at the macroscopic and microscopic levels.

The civil engineering graduate uses knowledge of materials science to *solve* problems appropriate to civil engineering. The materials science required for civil engineering practice must be learned at the undergraduate level and should prepare students for subsequent courses in engineering curricula.

MATERIALS SCIENCE			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
Define material properties through key concepts in physics and chemistry	Explain material properties through key concepts in physics and chemistry	Apply knowledge of materials, such as concrete, steel, soils, and asphalt, used in civil engineering construction	Analyze a complex problem to determine the relevant materials science principles, and then apply that knowledge to solve the problem

Mechanics

In its original sense, mechanics refers to the study of the behavior of systems under the action of forces. Mechanics is subdivided according to the types of systems and phenomena involved. An important distinction is based on the size of the system. The Newtonian laws of classical mechanics can adequately describe those systems that are encountered in most civil engineering areas.

Mechanics in civil engineering encompasses the mechanics of continuous and particulate solids subjected to load, and the mechanics of fluid flow through pipes, channels, and porous media. Areas of civil engineering that rely heavily on mechanics are structural engineering, geotechnical engineering, pavement engineering, and water resource systems.

The civil engineering graduate analyzes and solves problems in solid and fluid mechanics. The mechanics required for civil engineering practice must be learned at the undergraduate level and should prepare students for subsequent courses in engineering curricula.

MECHANICS			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
Intentionally left blank	Explain key concepts and problem-solving processes in statics, dynamics, and solid and fluid mechanics	Analyze and solve problems involving solid and fluid mechanics	Evaluate the validity of newly-created knowledge in mechanics

Experiments

Experiment can be defined as "an operation or procedure carried out under controlled conditions in order to discover an unknown effect or law, to test or establish a hypothesis, or to illustrate a known law."

Civil engineers frequently design and conduct field and laboratory studies, gather data, create numerical simulations and other models, and then analyze and interpret the results. Individuals should be familiar with the purpose, procedures, equipment, and practical applications of experiments spanning more than one of the technical areas of civil engineering. They should be able to conduct experiments, report results, and analyze results in accordance with the applicable standards in or across more than one technical area. In this context, experiments may include field and laboratory studies, virtual experiments, and numerical simulations.

The civil engineering graduate analyzes the results of experiments and evaluates the accuracy of the results within the known boundaries of the tests and materials in or across more than one of the technical areas of civil engineering.

EXPERIMENTS			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
Conduct experiments in natural science courses according to established procedures, report results, and evaluate the accuracy of the results	Explain the purpose, procedures, equipment, and practical applications of experiments in natural sciences	Conduct experiments in civil engineering according to established procedures, report results, and evaluate the accuracy of the results within the known boundaries of the test and materials	Specify an experiment to meet a need, conduct the experiment, and analyze and evaluate the experiment for effectiveness in meeting a real-world need

Design

Design is an iterative process that is often creative and involves discovery and the acquisition of knowledge. Such activities as problem definition, the selection or development of design options, analysis, detailed design, performance prediction, implementation, observation, and testing are parts of the engineering design process.

Design problems are often ill-defined, so defining the scope and design objectives and identifying the constraints governing a particular problem are essential to the design process. The design process is open-ended and involves a number of likely correct solutions, including innovative approaches. Successful design requires critical thinking, an appreciation of the uncertainties involved, and the use of engineering judgment. Consideration of risk assessment, societal and environmental impact, standards, codes, regulations, safety, security, sustainability, constructability, and operability are integrated at various stages of the design process.

The civil engineering graduate designs a system or process to meet desired needs within such realistic constraints as economic, environmental, social, political, ethical, health and safety, constructability, and sustainability.

DESIGN			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
Intentionally left blank	Identify basic purpose and steps of design process as problem solvers	Apply the design process to create a solution while meeting the requirements of real-world constraints	Evaluate design of complex systems and assess compliance with standards of practice, user needs, and relevant constraints

Multidisciplinary Teamwork

Licensed civil engineers must be able to function as members of a team. This cooperation requires understanding team formation and evolution, personality profiles, team dynamics, collaboration among diverse disciplines, problem solving, and time management, and being able to foster and integrate diversity of perspectives, knowledge, and experiences.

A civil engineer will eventually work within two different types of teams. The first is intra-disciplinary and consists of members from within the civil engineering sub-discipline—for example, a structural engineer working with a geotechnical engineer. The second is multidisciplinary and is a team composed of members of different professions—for example, a civil engineer working with an economist on the financial implications of a project or a civil engineer working with local elected officials on a public planning board. Multidisciplinary also includes a team consisting of members from different engineering sub-disciplines—sometimes referred to as a cross-disciplinary team—for example, a civil engineer working with a mechanical engineer.

The civil engineering graduate functions effectively as a member of an intra-disciplinary team. At the undergraduate level, the focus is primarily on working as members of an intra-disciplinary team—that is, a team within the civil engineering sub-discipline. Examples of opportunities for students to work in teams include design projects and laboratory exercises within a course and during a capstone design experience.

MULTIDISCIPLINARY TEAMS			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
Have experience in collaborative learning and teamwork on class projects	Discuss and demonstrate collaborative learning and teamwork on class projects	Function effectively as a member of an interdisciplinary team	Function effectively as a member of a multidisciplinary team

Problem Solving and Recognition

Civil engineering problem solving consists of identifying engineering problems, obtaining background knowledge, understanding existing requirements and/ or constraints, articulating the problem through technical communication, formulating alternative solutions—both routine and creative—and recommending feasible solutions.

Appropriate techniques and tools— including information technology, contemporary analysis and design methods, and design codes and standards to complement knowledge of fundamental concepts—are required to solve engineering problems. Problem solving also involves the ability to select the appropriate tools as a method to promote or increase the future learning ability of individuals.

The civil engineering graduate develops problem statements and *solves* well-defined fundamental civil engineering problems by *applying* appropriate techniques and tools. Civil engineers should be familiar with factual information related to engineering problem recognition and problem-solving processes. Additionally, civil engineers should be able to explain key concepts related to engineering problem recognition, articulation, and solving.

PROBLEM RECOGNITION AND SOLVING			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
Explain key concepts related to problem recognition, problem articulation, and problem-solving processes related to math and science applications	Identify key factual information related to math, science, and basic mechanics problem recognition, problem solving, and applicable techniques and tools	Develop problem statements and solve fundamental civil engineering problems by applying appropriate techniques and tools in at least four technical areas	Synthesize the solution to an engineering problem into a broader public, policy, social impact, or business objective

Ethics

Civil engineers in professional practice have a privileged position in society, affording the profession exclusivity in the design of the public's infrastructure. This position requires each of its members to adhere to a doctrine of professionalism and ethical responsibility. This doctrine is set forth in the seven fundamental canons in the American Society of Civil Engineer's (ASCE) Code of Ethics. The first canon states that civil engineers "…shall hold paramount the safety, health, and welfare of the public.…" By meeting this responsibility, which puts the public interest above all else, the profession earns society's trust.

Civil engineers aspire to be "entrusted by society to create a sustainable world and enhance the global quality of life." Therefore, current and future civil engineers, whether employed in public or private organizations or self-employed, will increasingly hold privileged and responsible positions.

The civil engineering graduate analyzes a situation involving multiple conflicting professional and ethical interests to determine an appropriate course of action. The undergraduate experience should introduce and illustrate the impact of the civil engineer's work on society and the environment. This experience naturally leads to the importance of meeting such professional responsibilities as maintaining competency and the need for ethical behavior.

ETHICS			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
Intentionally left blank	Identify appropriate academic and professional ethical behaviors	Analyze a situation and apply standards of professional and ethical responsibility to determine appropriate action	Synthesize studies and experiences to foster professional and ethical conduct

Communication

Means of communication include listening, observing, reading, speaking, writing, and graphics. The civil engineer must communicate effectively with technical and non-technical individuals and audiences in a variety of settings. Use of these means of communication by civil engineers requires an understanding of communication within professional practice. Fundamentals of communication should be acquired during formal education. Pre-licensure experience should build on these fundamentals to solidify the civil engineer's communication skills.

Within the scope of their practice, civil engineers prepare and/or use calculations, spreadsheets, equations, computer models, graphics, and drawings—all of which are integral to a typically complex analysis and design process. Implementation of the results of this sophisticated work requires that civil engineers communicate the essence of their findings and recommendations.

The civil engineering graduate organizes and *delivers* effective verbal, written, virtual, and graphical communications. Communication can be taught and learned across the curriculum—that is, over all of the years of formal education and in most courses.

COMMUNICATION			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
List and use basic elements of oral, written, virtual, and graphical communication	Apply the rules of grammar and composition in verbal and written communications, properly cite sources, and use appropriate graphical standards in preparing engineering drawings	Organize and deliver effective oral, written, virtual, and graphical communication	Evaluate the effectiveness of the integrated verbal, written, and graphical communication of a project to technical and non-technical audiences

Contemporary Issues and Historical Perspectives

To be effective, professional civil engineers should draw upon their broad education to analyze the impacts of historical and contemporary issues on engineering and analyze the impact of engineering on the world. The engineering design cycle illustrates the dual nature of this outcome. In defining, formulating, and solving an engineering problem, engineers must consider the impacts of historical events and contemporary issues.

Examples of contemporary issues that could impact engineering include the multicultural globalization of engineering practice; raising the quality of life around the world; the importance of sustainability; the growing diversity of society; and the technical, environmental, societal, political, legal, aesthetic, economic, and financial implications of engineering projects. When generating and comparing alternatives and assessing performance, engineers must also consider the impact that engineering solutions have on the economy, environment, political landscape, and society.

The civil engineering graduate draws upon a broad education; *explains* the impact of historical and contemporary issues on the identification, formulation, and solution of engineering problems; and *explains* the impact of engineering solutions on the economy, environment, political landscape, and society.

CONTEMPORARY ISSUES AND HISTORICAL PERSPECTIVES			
Core Competencies Needed to enter Higher Education in Civil Engineering	**Pre-Engineering Competencies gained during first two years of study**	**Baccalaureate Level Engineering Competencies**	**Graduate Level Engineering Competencies**
Describe economic, environmental, public policy, and societal aspects of modern history	Explain the impact of engineering solutions on the economy, environment, public policy, and society	Understand historical and contemporary issues and apply their impacts in solution of engineering problems	Evaluate the impacts and relationships among engineering and historical, contemporary, and emerging issues

NOTE: After review of the survey results to date (April 28, 2011), the Civil Engineering Tuning Committee concludes that the faculty survey results were quite useful for positive improvement of the expertise and employment profiles. The survey results for the educational competencies were largely in agreement with the wording and concepts that we took from the ASCE BOK2E. We recognize that the BOK2E is a work in progress, but it provided a useful framework for the Lumina project. We also note that the list of competencies is not a set of minimum legal standards, but rather frames the discussion of topics and levels of achievement desired in early and later college years.

Community College Program of Study for Transfer to an Civil Engineering Program

FRESHMAN YEAR

First Semester (Fall)

Course		SCH
MATH 2413	Calculus I	4
CHEM 1300	General Chemistry	3
CHEM 1111	Chemistry I Laboratory	1
ENGR 1201	Introduction to Engineering	2
XXXX ####	Texas Core Curriculum Requirement	3
XXXX ####	Texas Core Curriculum Requirement	3
	Semester Credit Hours	**16**

Second Semester (Spring)

Course		SCH
MATH 2414	Calculus II	4
PHYS 2325	University Physics I	3
PHYS 2125	University Physics I Laboratory	1
ENGR 1304	Engineering Graphics	3
XXXX ####	Texas Core Curriculum Requirement	3
XXXX ####	Texas Core Curriculum Requirement	3
	Semester Credit Hours	**17**

SOPHOMORE YEAR

First Semester (Fall)

Course		SCH
MATH 2415	Multi-Variable Calculus (Calculus III)	4
ENGR 1307	Plane Surveying	3
ENGR 2301	Engineering Mechanics: Statics	3
ENGR 2304	Programming for Engineers	3
XXXX ####	Texas Core Curriculum Requirement	3
	Semester Credit Hours	**16**

Second Semester (Spring)

Course		SCH
MATH 2320	Differential Equations	3
PHYS 2326	University Physics II *or* ENGR 2305 Electrical Circuits I	3
PHYS 2126	*or* ENRG 2105 Electrical Circuits I Lab	1
ENGR 2302	Engineering Mechanics: Dynamics	3
XXXX ####	Texas Core Curriculum Requirement	3
XXXX ####	Texas Core Curriculum Requirement	3
	Semester Credit Hours	**16**

Notes:

1. Texas Common Course Numbers are used for all TCCN-numbered courses.
2. Some civil engineering programs require Chemistry II in addition to Chemistry I. The student is advised to check with the school to which he or she intends to transfer for specific requirements.
3. Either Physics II or Circuit Analysis may be required.
4. Some civil engineering programs will accept the course ENGR 1201 for transfer credit and as applicable to the engineering major, while others will accept the course for transfer credit only. The student is advised to check with the school to which he or she intends to transfer for specific applicability of this course to the engineering major.
5. Civil engineering programs will accept the course COSC 1436/1336 in place of ENGR 2304.

Prerequisite Flowchart