AC 2011-2251: "TUNING" ENGINEERING PROGRAMS IN THE CONTEXT OF ABET ACCREDITATION

Mary Eileen Smith, Ph.D., Texas Higher Education Coordinating Board

Mary E. Smith has been employed with the Texas Higher Education Coordinating Board since 1987 and now serves as Assistant Deputy Commissioner for Academic Planning and Policy. She is responsible for the administration and management of matters related to the Board's higher education academic planning and policy functions, and she provides leadership on key projects, reports, and studies that cut across divisions of the agency. She has taught at The University of Texas at Austin, and she currently is an Adjunct Assistant Professor of Communication at St. Edward's University in Austin.

Smith serves as the project coordinator for the $1.8 million productivity grant awarded to Texas from Lumina Foundation for Education to plan methods of making the opportunity of going to college more affordable for students and the state. Smith has organized numerous meetings and conferences on behalf of the Coordinating Board, and she has made a number of presentations at various academic and professional conventions and conferences. Smith served for five years as a program director in the former Division of Universities and Health-Related Institutions where her primary responsibilities included the review of new degree program proposals and the administration of the Minority Health Research and Education Grant Program. Smith spent her first 12 years of employment with the Coordinating Board in the Department of Personnel Services, where from 1996 to 1999 she served as the department's assistant director. Prior to her employment with the Coordinating Board, Smith spent 13 years in the health care field.

Smith holds a Ph.D. in Communication Studies, a Certificate in Dispute Resolution, a Master of Arts degree in Speech Communication, and a Bachelor of Arts degree in Psychology, all from The University of Texas at Austin.

James K. Nelson, The University of Texas at Tyler

Dr. James K. Nelson received a Bachelor of Civil Engineering degree from the University of Dayton in 1974. He received the Master of Science and Doctor of Philosophy degrees in civil engineering from the University of Houston. During his graduate study, Dr. Nelson specialized in structural engineering. He is a registered professional engineer in four states, a Chartered Engineer in the United Kingdom, and a fellow of the American Society of Civil Engineers. He is also a member of the American Society for Engineering Education and the SAFE Association. Prior to receiving his Ph.D. in 1983, Dr. Nelson worked as a design engineer in industry and taught as an adjunct professor at the University of Houston and Texas A&M University at Galveston. In industry he was primarily involved in design of floating and fixed structures for the offshore petroleum industry. After receiving his Ph.D., Dr. Nelson joined the civil engineering faculty at Texas A&M University. He joined the civil engineering faculty at Clemson University in 1989 as Program Director and founder of the Clemson University Graduate Engineering Programs at The Citadel and became Chair of Civil Engineering in 1998. In July 2002, Dr. Nelson joined the faculty at Western Michigan University as Chair of Civil and Construction Engineering. At Western Michigan he started the civil engineering undergraduate and graduate degree programs and also chaired the Departments of Materials Science and Engineering and Industrial Design. In summer 2005 he joined the faculty at The University of Texas at Tyler. At UT Tyler he was the founding chair of the Department of Civil Engineering and instituted the bachelor's and master's degree programs. In 2006 he became the Dean of Engineering and Computer Science. Dr. Nelson's primary technical research interest is the behavior of structural systems. For almost 25 years he has been actively involved in evaluating the behavior of free-fall lifeboats and the development of analytical tools to predict that behavior. His research has formed the basis for many of the regulations of the International Maritime Organization for free-fall lifeboat performance. Since 1998, Dr. Nelson has served as a technical advisor to the United States Delegation to the International Maritime Organization, which is a United Nations Treaty Organization. In that capacity, he is a primary author of the international recommendation for testing free-fall lifeboats and many of the international regulations regarding the launch of free-fall lifeboats. He has authored many technical papers that have been presented in national and international forums and co-authored three textbooks. Dr. Nelson chaired a national committee of the American Society of Civil Engineers for curriculum redesign supporting the civil engineering body of knowledge. He is actively engaged in developing strategies for enhancing the STEM education pipeline in Texas and nationally, and has testified before the Texas Senate in that regard. He served on a committee of the Texas Higher Education Coordinating Board to develop a statewide articulation compact for mechanical engineering. He also served on the Texas State Board of Education committee preparing the standards for career and technical education. He is currently serving on the Engineering Education Task Force of the National Council of Examiners for Engineering and Surveying.

David Walton Gardner, Ph.D., Texas Higher Education Coordinating Board

As Deputy Commissioner for Academic Planning and Policy and Chief Academic Officer, David W. Gardner leads the Coordinating Board's Planning and Accountability Division, the Academic Affairs and Research Division, and the Division of P-16 Initiatives. His primary responsibilities include coordination of the Board's efforts toward Closing the Gaps through academic excellence and research at Texas institutions of higher education.

Previously, Gardner served the agency as the Associate Commissioner for Academic Excellence and Research and as the Assistant Commissioner for Planning and Information Resources. Gardner provided leadership for statewide initiatives such as Texas' higher education plan Closing the Gaps by 2015, the college and university electronic library resource sharing consortium, the Texas Accountability System for Higher Education, and the Texas Public Education Information Resource, which includes information on all students enrolled in Texas public schools, as well as public and private higher education institutions in Texas.

Prior to joining the Coordinating Board staff in 1985, Gardner was on the faculty at Hofstra University where he taught in the master's and doctoral programs in the Administration and Policy Studies Department. While at Hofstra, he was director of the master's program, chaired the university's planning committee, and served on the graduate council and the scholarships committee. He has been a visiting professor at Texas A&M University, and is currently an Adjunct Professor of Higher Education at The University of Texas at Austin.

Gardner received his Ph.D. and Master's degrees from Texas A&M University and his Bachelor of Arts degree from the University of Houston.

"Tuning" Engineering Programs in the Context of ABET Accreditation

Abstract

As part of a four-year grant project sponsored by Lumina Foundation for Education, the State of Texas has embarked upon integrating the Tuning process into lower-division course-level alignment work that was piloted in 2009 through the efforts of the Voluntary Mechanical Engineering Transfer Compact Committee, a voluntary advisory committee comprised of engineering deans and their designees from across Texas. Over the grant period, with the help of voluntary higher education faculty advisory committees, the Tuning process, and the process of vertically and horizontally aligning lower-division courses, will be applied to 12 academic discipline areas. The process began in 2010 with four engineering disciplines. Presented in this paper are the basis and methodology used by the "Tuning Oversight Council for Engineering," which is comprised of engineering faculty members from across Texas, to tune the civil, industrial, electrical, and mechanical engineering disciplines, and to align lower-division courses among two- and four-year institutions to more fully and efficiently use the community college pathway to baccalaureate degrees in engineering.

Introduction

<u>Tuning as a Complement to ABET Accreditation Criteria</u>

"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 degree levels (i.e., associate's degree, bachelor's degree, etc.) – 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. Tuning can also define the competencies achieved through experience after formal education. Through Tuning, students have a clear "picture" of what is expected and can efficiently plan their educational experience to achieve those expectations. 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.

Criterion 2 and Criterion 3 of the ABET, Inc. criteria for accrediting engineering programs provide the foundation as well as the motivation for tuning engineering programs. Criterion 2 requires that each accredited program develop program educational objectives (PEOs), the career and professional accomplishments that the program is preparing its graduates to achieve at some point after graduation (typically five years after graduation). The PEOs are crafted by each program for its particular and unique mission. Criterion 3 provides for program outcomes, describing what students are expected to know and be able to do by the time of graduation. Some engineering disciplines specify additional outcomes that are expected of their graduates. For example, the American Society of Civil Engineers (ASCE) expects civil engineering baccalaureate graduates to have breadth as well as depth in multiple fields of civil engineering. For advanced programs (graduate programs), very little is specified in regard to program outcomes.

Tuning is complementary to ABET criteria for evaluating engineering programs in that Tuning seeks to define in specific and assessable terms the elements of the PEOs and the program outcomes with corresponding levels of achievement at critical milestones in the education of an engineer (or other professional). The Tuning process also calls upon disciplines to write Degree Profiles in terms of general and discipline-specific competencies their students will achieve at specified levels. Tuning thus facilitates demonstrating achievement of the program outcomes as students move through the educational process.

However, Tuning does not dictate to the faculty how to achieve these aims. This approach is consistent with the EAC/ABET Criterion 5, Curriculum, that explicitly avoids prescribing specific courses or other curricular details. Both ABET and Tuning explicitly recognize that different institutions and different programs have different missions, different student populations, and different employer groups. Thus, the details of individual programs must continue to be developed as appropriate for the individual institutions – all degrees in a given engineering discipline provide the same fundamental competencies, but how these are achieved will vary from institution to institution. Further, institutions and programs will likely develop additional PEO's and outcomes and associated competencies to support their unique missions.

Tuning Engineering Education in Texas

In 2000, the Texas Higher Education Coordinating Board (THECB) launched its ambitious strategic plan for higher education, *Closing the Gaps by 2015* (1). The plan focuses on bringing Texas to parity with the 10 most populous states in four critical areas of higher education: student participation, student success, academic excellence, and research. The plan has been widely embraced by education, business, political, and community stakeholders across the state.

Over the past 10 years, Texas has reached many significant milestones in *Closing the Gaps*, but Texas needs to accelerate the pace if it is going to meet the target of increasing the number of students who complete engineering, computer science, math, and physical science (STEM) bachelor's and associate's degrees, and certificates to 29,000 by 2015 (2, p. 20; 3). Further, given the current economic challenges facing Texas and its residents, achieving the goal of increasing the number of engineering graduates will require cost-effective methods.

One such method is to develop more cooperative programs between two-year and four-year institutions in which students can complete the first two years of postsecondary education at a lower-cost community college, and then transfer to a four-year university to complete the last two years of study for a bachelor's degree. This pathway is pursued by a significant percentage of students matriculating in Texas. Of the undergraduate students who first entered higher education in Texas in 2009, two-thirds began in community colleges (2, p. 4). Public two-year institutions in Texas accounted for 50 percent of the share of statewide enrollment in fall 2009 (2, p. 4). However, to better serve these community college students and help meet the state's target of increasing the number of students who successfully complete the baccalaureate degree, transfer between two- and four-year institutions needs to be made more efficient (as measured by total semester credit hours completed for graduation) and more understandable for students, parents, and advisors.

Particularly challenging with respect to baccalaureate engineering programs are analyses which show that transfer students historically have not been as successful at completing an engineering baccalaureate degree in a timely manner, as have "native" students (those who initially enroll at the university and complete an engineering degree at that university). For example, one of the key findings in a comprehensive pathway study of Texas engineering students indicated that students in the engineering cohort who started at a four-year institution had an engineering degree completion rate of 40 percent and an overall bachelor's completion rate of 62 percent, whereas students in the engineering cohort who started at a two-year institution had an engineering degree completion rate of 16 percent and an overall bachelor's completion rate of 26 percent (4). Similarly, a comparison of the completion rates of the 2005 junior cohort of native versus transfer students revealed that the overall completion rate for native engineering students at the end of the fourth year exceeded that of transfer students by 20-30 percent, depending on the engineering discipline (5).

Clearly, successfully using the community college as a cost-effective and efficient pathway to the baccalaureate in engineering will require fostering enhanced transfer processes between two- and four-year institutions and increased student understanding of and preparation for the educational process. To these ends, as part of a four-year grant project sponsored by Lumina Foundation for Education (Lumina), the State of Texas has embarked upon integrating the Tuning process into lower-division course-level alignment work that was piloted in 2009 through the efforts of the Voluntary Mechanical Engineering Transfer Compact Committee, a voluntary advisory committee comprised of engineering deans and their designees from across Texas. Over a four-year period, with Lumina's grant support and the help of voluntary higher education faculty advisory committees, the Tuning process will be applied to 12 academic discipline areas, beginning with engineering fields and other high-need STEM disciplines. In conjunction with the Tuning process, Texas will continue the process of vertically and horizontally aligning lower-division courses and refining the process of more fully and efficiently using the community college pathway to baccalaureate degrees in an effort to deliver high-quality, cost-effective education to a greater number of students. The specific goals of the four-year project are:

1) To create a framework that establishes clear program-level learning expectations for students in specified engineering or science discipline areas while balancing the need among programs to retain their academic autonomy and flexibility; and

2) To identify a set of lower-division courses, up to the level of a certificate or an associate's degree, that will provide the necessary academic background so students can migrate seamlessly into participating engineering or science programs at four-year institutions.

More detailed information regarding of the goals and procedures of the project is available at: http://www.thecb.state.tx.us/tuningtexas > Summary Information about the "Tuning Texas" Initiative.

Methodology

Selection of Disciplines in Texas

After extensive discussions among members of the "Texas Team" (comprised higher education, legislative, and business leaders), it was decided to tune four engineering disciplines during the first year of the grant period in the belief that the work would be leveraged across similar disciplines and could build on momentum gained from course-level alignment work already accomplished in mechanical engineering. The initial engineering disciplines selected for Tuning were civil, electrical, industrial, and mechanical engineering.

Introducing Tuning to Texas Stakeholders

In February 2010, meetings were held to introduce the concept and processes of Tuning to a representative group of Texas business leaders (morning of February 25), chancellors and presidents (afternoon of February 25), and engineering deans and department chairs (February 26). These introductory meetings were designed to increase the engagement of the business community and the awareness of higher education administrators in the Tuning process. Two staff members and two consultants from Lumina provided an overview of Tuning and insights as to how the process was applied in Minnesota, Utah, and Indiana.

Formation of the Tuning Council and Discipline-Specific Committees

In order to form the "Tuning Oversight Council for Engineering (Council)," staff members of the Texas Higher Education Coordinating Board (THECB) invited public universities in Texas that offer a bachelor's degree program in civil, electrical, industrial, or mechanical engineering, and a sample of public community colleges in Texas offering lower-division engineering courses (or prerequisites), to nominate a faculty representative for the Council. Fifteen universities and 15 community and technical colleges/districts nominated representatives. Faculty representatives were selected by THECB staff on the basis of the rationale submitted for each nominee, the nominee's vita, and the need to balance regional, university system, and community college district representation. Nominations for student representatives were solicited from Council members at the Council's initial meetings, and student representatives were selected by THECB staff on the basis of the same criteria used for faculty representatives. The final Council was comprised of: (a) university faculty representatives of four engineering disciplines (civil, electrical, industrial, and mechanical) from across the state; (b) four university engineering students, each representing different institutions and one of the four selected engineering disciplines; and (c) community college faculty representatives of engineering, math, and science disciplines. Specifically, The Tuning Oversight Council for Engineering is comprised of engineering deans, their designees, and STEM faculty representing the following institutions: Alamo Community College District; Amarillo College; Austin Community College; Collin County College; Dallas County Community College District; El Paso Community College District; Houston Community College System; Kilgore College; Lamar University; McLennan Community College; Midwestern State University; Northeast Texas Community College; Prairie View A&M University; San Jacinto College District; South Texas College; Tarrant County College District; Texas A&M University; Texas State Technical College-Harlingen; Texas State University-San Marcos; Texas Tech University; The University of Texas at Arlington; The University of Texas at Austin; The University of Texas at El Paso; The University of Texas of the Permian Basin; The University of Texas-Pan American; The University of Texas at San Antonio; The University of Texas at Tyler; Tyler Junior College; University of North Texas; and West Texas A&M University. A list of members is available online at: www.thecb.state.tx.us/tuningtexas > Tuning Oversight Council for Engineering.

Initial Organizational Meetings

The Tuning Oversight Council met for the first organizational meeting on April 20, 2010. Lumina staff members and guest faculty (with experience in tuning physics in Utah) provided an introduction to Tuning and described how the process had evolved in Utah. Specific charges for the Council's work were provided to all Council members, and a Chair and Co-chair of the Council were elected by members. Discipline-specific committees also met separately, selected their committee chairs and co-chairs, and reported out at the end of the meeting. However, a perceived potential conflict between ABET criteria for evaluating engineering programs and Tuning was an expressed concern of some engineering faculty during the first meeting and was evident from meeting evaluation forms. In order to help address these concerns, supply additional information on expected discipline-specific committee deliverables, and provide an opportunity for the committees to establish work plans, a second organizational meeting was held on May 21. The perceived potential conflict between ABET criteria for evaluating engineering programs and Tuning became less of a concern of engineering faculty represented on the Council as a result of continued discussion regarding the similarities and differences between Tuning and ABET evaluation criteria.

Face-to-Face Tuning Meetings

Council and discipline-specific committee meetings were held during 2010 and early 2011. The full Council met face-to-face for quarterly meetings on July 30, October 15, and January 7. A special face-to-face meeting for two-year college representatives of the Council was held on January 6 to discuss issues specifically related to the transfer of students from two- to four-year institutions. During the full Council meetings, information applicable to all four discipline-specific engineering committees was shared and discussed among all members of the Council prior to the four discipline-specific committees breaking into their own face-to-face meetings in separate rooms for continued Tuning work on their respective disciplines. Following their own discipline-specific discussions, committees reported out their progress to the full Council at the end of each of these face-to-face meetings.

Virtual Tuning Meetings

To minimize travel costs and to facilitate the work of the discipline-specific committees between face-to-face meetings, members of the four discipline-specific committees used webcams along with Live Meeting software to do much of their work online. SharePoint sites were created for each committee through which members communicated and shared working documents. A THECB "staff liaison" was assigned to each committee to assist the chairs and co-chairs and to facilitate the work of the committee members.

Student Surveys

Student general competency surveys for community college students enrolled in lower-division engineering courses (i.e., Introduction to Engineering, Circuits, Dynamics, or Statics) and for university students enrolled in senior-level design classes were finalized in Survey Monkey during the week of September 13, and the links to the surveys were released for distribution to students by Council members and their on-campus colleagues on September 20. A copy of the survey is available upon request to the authors. A synopsis of student survey results as compiled for the January 7, 2011, meeting of the Tuning Oversight Council for Engineering is presented as **Appendix A**.

Employer Surveys

There was much difficulty in securing actual employer contact information for survey completion requests from Council members, because members expressed the concerns of their respective department chairs and deans that the employers of their engineering graduates are being over-surveyed and may be reluctant to complete surveys needed for ABET accreditation if yet another survey was conducted for this project. Nevertheless, the survey for employers of engineering graduates was finalized in Survey Monkey during the week of October 25, with individual collection sites created for each institution so that institutions would be able to get individualized information from employers of their institution's graduates and be more motivated to distribute survey completion requests. Links to the survey were sent to specific institutions for distribution to their employer contacts on November 1, 2010. Links to the survey also were sent to certain employer contacts gathered by THECB staff. A copy of the survey is available upon request to the authors. A synopsis of preliminary employer survey results as compiled for the January 7, 2011, meeting of the Council is presented as **Appendix B.**

Results

At the time of this writing, discipline-specific committees continue to progress with the Tuning process and develop Tuning deliverables at different paces. Below is the summary progress as of January 7, 2011, for each of these discipline-specific committees. Final results of the committees' Tuning and course-alignment work will be available once the committees complete their respective work; incorporate the final results of general competency surveys of students, employers, recent graduates (still in progress at the time of this writing), and faculty (still in progress); and finalize their Tuning deliverables. This is anticipated to occur by the time of the Council's quarterly face-to-face meeting in April 2011. A statewide 30-day comment period for stakeholders of engineering education on these deliverables will follow this meeting.

Civil Engineering Committee

The Civil Engineering Committee has finished its work on the civil engineering competency table with the following categories: (1) core competencies needed to enter higher education in civil engineering; (2) pre-engineering competencies gained during first two years of study; (3) baccalaureate-level engineering competencies; and (4) post-graduate engineering competencies. As an example of this discipline-specific committee work product, the final draft of the Civil Engineering Competency Table is presented as **Appendix C**.

The Civil Committee's work has been informed by the American Society of Civil Engineers (ASCEE) *Civil Engineering Body of Knowledge for the 21st Century, 2nd Edition, 2008* (BOK2E). The Civil Committee, however, focused on current ABET-driven competency requirements, rather than on ASCEE goals for the future development of the profession.

The Civil Committee also finished its civil engineering key competencies profile, which is a schematic summary of the civil engineering competency table. As an example of this discipline-specific committee work product, the final draft of the Civil Engineering Key Competencies Profile is presented as **Appendix D**.

The Civil Committee established civil engineering profiles for expertise and employment. The expertise profile lists 10 types of coursework necessary for the completion of a baccalaureate degree in civil engineering, and the employment profile lists seven types of jobs available for civil engineers. As examples of these discipline-specific committee work products, the final drafts of the Civil Engineering Profiles for Expertise and Employment are presented as **Appendix E**.

The Civil Committee still has to complete work on one-page descriptions for outcome titles from the competency table.

Electrical Engineering Committee

The Electrical Engineering Committee has finished its work on its 16 program-level outcomes (summaries) and the electrical engineering key competencies profile.

The Electrical Committee's work was informed by the common and non-common elements of program outcomes found at the University of North Texas, The University of Texas at Arlington, The University of Texas at Tyler, and Prairie View A&M University. The Electrical Committee's work was also informed by the 2010-2011 ABET Criteria for Electrical, Computer, and similarly named engineering programs (Lead Society: Institute of Electrical and Electronics Engineers; Cooperating Society for Computer Engineering Programs: CSAB).

The Electrical Committee still has to complete work on the definition of the discipline, key competencies by educational level, and expertise/employment profile.

Industrial Engineering Committee

The Industrial Engineering Committee is progressing on work toward completing the following five deliverables, with an estimated percentage completion level as noted:

(1) Definitions of industrial engineering competencies at various levels (80 percent complete);

(2) Key competencies profile of Industrial Engineering – schematic summary of the industrial engineering competency table (90 percent complete);

(3) Industrial Engineering expertise profile (80 percent complete);

(4) Industrial Engineering employment profile (80 percent complete); and

(5) Outcome title description pages for Industrial Engineering (50 percent complete).

Mechanical Engineering Committee

The Mechanical Engineering Committee is making progress on the identification of baccalaureate-level outcomes for mechanical engineering graduates.

The Mechanical Committee has completed the competency table with enhanced program-level outcomes based on ABET criteria A-K, and the Mechanical Committee has nearly completed the identification of the level of competency (based on Bloom's taxonomy) for all of the program-level outcomes.

The Mechanical Committee still has to complete work on the one-page descriptions for the outcomes.

Discussion

Reaching the goals of the state's higher education plan, *Closing the Gaps by 2015,* will be a significant accomplishment for Texas. Gains in higher education have the potential to strengthen Texas' economic base, attract innovative businesses and top-flight faculty to the state, generate research funding, improve quality of life, and enhance the overall stature of the state (6). It is expected that applying the Tuning process to high-need discipline areas and better aligning lower-division courses among two- and four-year institutions will assist the state in achieving the goals of the plan.

Tuning is a faculty-driven process that aims to define what students are expected to know, understand, and be able to do when they graduate from a program; to align these expectations with the needs of employers and society; to keep the expectations realistic and consistent with students' actual experience; and to make these expectations clear and transparent to a wide audience. Tuning addresses one discipline at a time and is the process whereby faculty carefully define learning outcomes essential to qualify for a degree in the discipline. "Tuning" is an apt term to describe this process because it involves harmonizing the approaches of various kinds and levels of institutions with diverse missions and student populations. By defining common demonstrable learning outcomes, the diverse institutions do not standardize their curricula or programs, but they focus these educational programs according to their own needs and strengths so as to achieve common outcomes.

Tuning takes place with input from faculty, students, alumni, and employers in order to retain clear grounding in the realities of needed skills and abilities as well as retaining perspective on realistic student workloads and expectations. The audience for Tuning extends beyond these participating groups to prospective students, parents, policymakers, funding groups, and a wider group of employers. This diverse audience can use the transparent picture provided by Tuning of what a student will achieve in a degree program and how that achievement can be useful to the student and to potential employers and society.

Tuning emphasizes transparency in learning outcomes and degree definitions so that prospective students and parents, interested observers from other disciplines, employers, and policy makers can see clearly what students are expected to know, understand, and be able to do when they graduate from a program (i.e., the knowledge, skills, and attitudes they are to have developed at program milestones). They can also see what kind of employment opportunities a graduate might reasonably expect. This transparency allows students and parents to make better informed choices at the outset of a program, making it possible them to plan a more efficient and cost-effective educational path that meets the needs of the individual student.

Course-level alignment is the process of assuring consistency of course outcomes across institutions. The products of course-level alignment allow course transfer among institutions with confidence that students will have similar abilities and knowledge. Course-level alignment is also not a process for standardizing curricula. Rather, the ways different institutions achieve the course-level outcomes will depend on the nature, student populations, strengths, and opportunities of each institution. Course-level alignment is primarily a faculty process, using the learning outcomes developed in the broader Tuning process that include employer, alumni, and student contributions as well as faculty leadership. Course-level alignment should grow out of Tuning by assigning elements of the demonstrable program-level learning outcomes identified in the Tuning process to individual courses. The role of the course in the program is thereby clarified, and alignment is motivated by the connection of the course goals and learning outcomes to the discipline's goals and learning outcomes for the degree.

Conclusion and Looking Ahead

Increasing the number of graduates in such fields as engineering and computer science has been identified as being vital to the long-term prosperity of the State of Texas. For example, the Texas Industry Cluster Initiative introduced by Governor Rick Perry in 2004 (7) focuses on building a competitive advantage through six target industry clusters, which are believed to offer overall economic growth and bring high-paying jobs to Texas. The industry clusters include advanced technologies and manufacturing, aerospace and defense, biotechnology and life sciences, information and computer technology, petroleum refining and chemical products, and energy. As Texas economist Ray Perryman has observed, all of these clusters have a clear need for engineers and computer scientists (8).

Over the remaining years of the four-year grant period, with the help of additional voluntary advisory committees made up of higher education faculty from across Texas, the Tuning process, and the process of vertically and horizontally aligning lower-division courses, will be applied to additional academic discipline areas, beginning in early 2011 with two more engineering disciplines, biology, and chemistry. Such work will begin with the initial face-to-face meeting on February 25, 2011, of the "Tuning Oversight Council for Engineering and Science," which will be comprised of biomedical engineering, chemical engineering, biology, and chemistry faculty members from across Texas.

References

1. Texas Higher Education Coordinating Board. (2000). *Closing the Gaps by 2015*. Retrieved from http://www.thecb.state.tx.us/reports/PDF/0379.PDF

2. Texas Higher Education Coordinating Board. (2010a). *Closing the Gaps Progress Report 2010*. Retrieved from http://www.thecb.state.tx.us/reports/PDF/2045.PDF

3. Texas Higher Education Coordinating Board. (2010b). *Accelerated Plan for Closing the Gaps by 2015*. Retrieved from http://www.thecb.state.tx.us/reports/PDF/2005.PDF

4. Texas Higher Education Coordinating Board. (2009). *Making Education Affordable Engineering Articulation Fact Book: Texas Public Institutions of Higher Education*. Retrieved from http://www.thecb.state.tx.us/reports/pdf/1832.pdf

5. Texas Higher Education Coordinating Board. (2010c). *Projecting the Need for Engineering Education in Texas*. Draft staff report to the Texas Higher Education Coordinating Board, August 2010.

6. The Perryman Group. (2007a). *"A Tale of Two States—And One Million Jobs!!" An Analysis of the Economic Benefits of Achieving the Future Goals of the "Closing the Gaps" Initiative of the Texas Higher Education Coordinating Board*. Retrieved from http://www.thecb.state.tx.us/reports/PDF/1345.PDF

7. Office of the Governor – State of Texas. (2004). *Texas Industry Cluster Initiative*. Retrieved from http://www.twc.state.tx.us/news/ticluster.html

8. The Perryman Group. (2007b). *The Potential Impact of an Initiative to Increase the Pool of Engineering and Computer Science Graduates on Business Activity in Texas.* Retrieved from http://www.thecb.state.tx.us/AAR/PerrymanGroup-EngCSreport-2007

Acknowledgements

The authors would like to acknowledge and thank Lumina Foundation for Education for its grant support and its Vision for 2025. The authors would also like to acknowledge and thank William (Bill) Evenson, Ph.D., Director of the Utah Tuning Project and consultant for the Utah System of Higher Education, for his assistance with the Tuning process in Texas. Finally, the authors would like to thank the members of Tuning Oversight Council for Engineering for their hard work and effort throughout the process.

Appendix A — Synopsis of Student Survey Results

<u>Community College Student Survey</u> (291 respondents)

1. Four respondents indicated they are not community college students, at which time they were directed to the "end of the survey" page, without permission to complete the survey. 194 respondents completed the survey.
2. The skill or competency having the **strongest** <u>workplace</u> importance is the "ability to work in a team" and the **strongest** <u>program development</u> emphasis is "knowledge and understanding of subject area/profession."
3. The skills or competencies ranked as "most important" overall are: 1) knowledge and understanding of subject area/profession; 2) applying knowledge in practical situations; 3) applying knowledge in practical situations with "working in a team" as a close contender for third ranking; 4) plan and manage time; and 5) three-way tie between "working in a team," "ability to evaluate/maintain quality of work," and "apply knowledge in practical situations."

<u>Four-Year Student Survey</u> (283 respondents)

1. Four respondents indicated they were not four-year college students, at which time they were directed to the "end of the survey" page, without permission to complete the survey. 172 respondents completed the survey.
2. The skills or competencies ranked as the "most important" overall are: 1) knowledge and understanding of subject area/profession; 2) working in a team; 3) a tie between "ability to design and manage projects" and "working in a team;" 4) a tie between "design and manage projects" and "ability to plan and manage time;" and 5) a tie between "working in a team" and "oral and written communication."
3. Selections for program development emphasis for the "ability to work in an international context" are nearly even across the scale, whereas the majority of respondents indicated it as having **considerable** workplace importance.

<u>Comparison Analysis of Community College and Four-Year Students</u>

- The majority of both community college and four-year student survey respondents indicate that "working in a team" and "knowledge and understanding of subject area/profession" as both **strong** in workplace importance and **strong** in program emphasis. The remaining skills/competencies cited as strong in both areas are unique to each group of respondents (two-year and four-year students) and do not overlap.
- The majority of both community college and four-year students indicate there is **no** program emphasis on the "ability to communicate in a second language."
- The majority of both community college and four-year students indicate there is **considerable** and/or **strong** workplace importance for the skill/competency of the "ability to show awareness of equal opportunities and gender issues." While community college students also indicate **strong** program emphasis for this skill/competency, four-year students indicate **weak** and **considerable** program emphasis.

Appendix B — Synopsis of Employer Survey Results

<u>Engineering Employer Survey</u> (199 respondents, as of January 4, 2011)

1. 30 of the 199 respondents indicated they do not employ engineering professionals, at which time they were directed to the “end of the survey” page, without permission to complete the survey. 169 respondents completed the survey.
2. The majority of respondents indicated their professional role as “CEO/President” or “Other.” The role of manager and director are the most commonly indicated professional roles in the “Other” category.
3. The majority of respondents indicated their organization’s industry sector as “Professional, Scientific, and Technical Services” and “Manufacturing.” The chemical industry, aerospace, and research were most often listed in the comments section for this question.
4. The majority of respondents indicated mechanical and electrical engineering as the engineering fields that apply to their organization’s work.
5. On a four-point Likert Scale (none, weak, considerable, and strong), the skills or competencies ranked as "most important" overall:.
   <u>#1 Knowledge and understanding of subject area/profession</u>: Employers indicated **considerable** demonstration by recent graduates
   <u>#2 Design and manage projects</u>: Employers indicated **weak** demonstration by recent graduates
   <u>#3 Oral and written communication</u>: Employers indicated **both weak and considerable** demonstration by recent graduates
   <u>#4 Work in a team</u>: Employers indicated **considerable** demonstration by recent graduates
   <u>#5 Oral and written communication</u>: Employers indicated **both weak and considerable** demonstration by recent graduates
6. The majority of respondents indicated each skill or competency as either having weak or considerable demonstration by recent graduates (few respondents indicated either “no demonstration by recent graduates” or “strong demonstration by recent graduates”)
7. The majority of respondents indicated either **weak or considerable** levels of demonstration by recent graduates in the following skills/competencies:
   a) <u>**Weak** levels of demonstration</u>:
      1. Ability to offer constructive feedback to others;
      2. Ability to design and manage projects;
      3. Ability to be self-critical; and
      4. Ability to motivate people and have common goals.

   b) <u>**Considerable** levels of demonstration</u>:
      1. Ability to work in a team (#4 overall ranking);
      2. Knowledge and understanding of subject area/profession (#1 overall ranking);
      3. Ability to communicate graphically and understand graphs, diagrams, plans, and blueprints; and
      4. Ability to act with social responsibility/civic awareness.
8. The importance of two skills/competencies is indicated as **strong and considerable** in the workplace with insufficient levels of demonstration by recent graduates:

   a) The ability to design and manage projects is indicated as a **strong** workplace skill/competency with **weak** demonstration by recent graduates.
   b) The ability to communicate with non-experts regarding one’s field is indicated as a **considerable** workplace skill/competency with **weak** demonstration by recent graduates.

Appendix C — Final Draft of the Civil Engineering Competency Table

Civil Engineering Key Competencies by Educational Level — Lumina Foundation Grant Civil Engineering Committee - October 15, 2010

Competencies	Mathematics	Natural Sciences	Materials Science	Mechanics	Experiments	Design	Teamwork	Problem Recognition and Solving	Ethics	Communication	Contemporary Issues and Historical Perspectives
Post-Graduate Engineering Competencies	Analyze a complex problem to determine the relevant mathematical principles and then apply that knowledge to solve the problem	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.	Analyze a complex problem to determine the relevant materials science principles, and then apply that knowledge to solve the problem.	Evaluate the validity of newly created knowledge in mechanics.	Specify an experiment to meet a need, conduct the experiment and analyze and evaluate the experiment for effectiveness in meeting a real-world need.	Evaluate design of complex system and assess compliance with standards of practice, user needs, and relevant constraints.	Function effectively as a member of a multidisciplinary team	Synthesize the solution to an engineering problem into a broader public, policy, social impact, or business objective.	Synthesize studies and experiences to foster professional and ethical conduct	Evaluate the effectiveness of the integrated verbal, written, and graphical communication of a project to technical and nontechnical audiences.	Evaluate the impacts and relationships among engineering and historical, contemporary, and emerging issues.
Baccalaureate Level Engineering Competencies	Solve problems in mathematics through differential equations and apply this knowledge to the solution of engineering problems	Solve problems in calculus-based physics, chemistry, and one additonal area of natural science and apply this knowledge to the solution of engineering problems	Apply knowledge of materials, such as concrete, steel, soils, and asphalt, used in civil engineering construction	Analyze and solve problems involving solid and fluid mechanics	Conduct experimetns 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	Apply the design process to create a solution while meeting the requirements of real-world constraints	Function effectively as a member of an interdisciplinary team	Develop problem statements and solve fundamental civil engineering problems by applying appropriate techniques and tools in at least four technical areas	Analyze a situation and apply standards of professional and ethical responsibility to determine appropriate action	Organize and deliver effective oral, written, virtual, and graphical communication	Understand historical and contemporary issues and apply their impacts in solution of engineering problems
Pre-Engineering Competencies gained during first two years of study	Explain key concepts and problem-solving processes in mathematics through differential equations	Explain key concepts and problem-solving processes in chemistry, calculus-based physics, and one additional area of natural science	Explain material properties though key concepts in physics and chemistry	Explain key concepts and problem-solving processes in statics, dynamics, and solid and fluid mechanics	Explain the purpose, procedures, equipments, and practical applications of experiments in natural sciences	Identify basic purpose and steps of design process as problem solvers	Discuss and demonstrate collaborative learning and team work on class projects	Identify key factual information related to math, science, and basic mechanics problem recognition, problem solving, and applicable techniques and tools	Identify appropriate academic and professional ethical behaviors	Apply the rules of grammar and composition in verbal and written communications, properly cite sources, and use appropriate graphical standards in preparing engineering drawings	Explain the impact of engineering solutions on the economy, environment, public policy, and society
Core Competencies needed to enter higher education in civil engineering	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 in physics, chemistry, and biology and solve related problems	Define material properties though key concepts in physics and chemistry		Conduct experiments in natural science courses according to established procedures, report results, and evaluate the accuracy of the results		Have experience in collaborative learning and team work on class projects	Explain key concepts related to problem recognition, problem articulation, and problem solving processes related to math and science applications		List and use basic elements of oral, written, virtual, and graphical communication	Describe economic, environmental, public policy, and societal aspects of modern history
Competencies	**A. Mathematics, Science, Engineering**				**B. Experiments**	**C. Design**	**D. Multi disciplinary Teams**	**E. Engineering Problems**	**F. Ethics and Professional Responsibility**	**G. Communication**	**H/J. Impact of Engineering and Contemporary Issues**

Civil Engineering Learning Outcome Descriptions

<u>Mathematics</u>

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.

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.

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.

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.

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.

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.

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.

Problem Recognition and Solving

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.

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 Engineers (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.

Communication

Means of communication include listening, observing, reading, speaking, writing, and graphics. The civil engineer must communicate effectively with technical and nontechnical 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 years of formal education and in most courses.

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.

Appendix D — Final Draft of the Civil Engineering Key Competencies Profile

Civil Engineering Key Competencies Profile

Lumina Foundation Grant Civil Engineering Committee - October 15, 2010

	Mathematics	Natural Sciences	Materials Science	Mechanics	Experiments	Design	Teamwork	Problem Recognition and Solving	Ethics	Communication	Contemporary Issues and Historical Perspectives
Evaluations				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

G	post-graduate competencies
BS	bachelaureate level competencies
CC	pre-engineering competencies
HS	secondary education competencies

Appendix E — Final Draft of the Civil Engineering Profiles for Expertise and Employment