A Civil Engineering Curriculum for the 21st Century

James K. Nelson, Osama Abudayyeh, Edmund Tsang, and Molly Williams
Western Michigan University, Kalamazoo, Michigan

Introduction

The computer "revolution" that occurred toward the end of the 20th century probably changed forever the background of the student entering engineering programs and the manner in which that student is best suited to learn. Further, the technology revolution has changed the manner in which engineering design is conducted and the needed skills of engineering professionals. This change is being recognized by the professional engineering organizations, which are now considering increased educational requirements for licensure. The American Society of Civil Engineers[1], in its policy statement on professional licensure, states that:

> *The civil engineering profession is undergoing significant, rapid, and revolutionary changes that have increased the body of knowledge required of the profession. These changes include the following:*
>
> - *Globalization has challenged the worldwide geographic boundaries normally recognized in the past, primarily as a result of enhanced communication systems.*
> - *Information technology has made, and continues to make, more information available; however, the analysis and application of this information is becoming more challenging.*
> - *The diversity of society is challenging our traditional views and people skills.*
> - *New technologies in engineering and construction are emerging at an accelerating rate.*
> - *Enhanced public awareness of technical issues is creating more informed inquiry by the public of the technical, environmental, societal, political, legal, aesthetic, and financial implications of engineering projects.*
> - *Civil infrastructure systems within the United States are rapidly changing from decades of development and operation to the renewal, maintenance, and improvement of these systems.*
>
> *These changes have created a market requiring civil engineers to have simultaneously greater breadth of capability and specialized technical competence than that required of previous generations. For example, many civil*

> *engineers must increasingly assume a different primary role from that of designer to that of team leader. ...*

Engineering programs need to respond to these changes so that graduates of the programs are prepared to enter the engineering workforce. The computational technology that is now available allows students to explore and to develop a firm understanding of the behavior of engineering systems, as well as the significance of the parameters affecting that behavior. Through utilization of the computational technology throughout the educational program, the technology becomes a tool in the solution process rather than the solution itself or the way in which the solution is obtained. Because of the capabilities of the computational tools, open-ended design problems can be readily introduced into course requirements on a regular basis because less time need be devoted to complex calculation and students can explore the implication of the various design parameters on the system. Heretofore, open-ended problems could not be assigned, except perhaps as a final project, because of the significant time required to perform routine calculations. Consequently, students have historically viewed design as being focused on individual components instead of on an entire system. Now, with extended computational and modeling tools available, engineers and engineering students can view design from the system level.

Further, the contemporary engineering design office has embraced the concept of design teams in the past several years. Depending upon the project, the design teams can be single-discipline or multi-discipline. By using teams as integral parts of the educational process, students develop interpersonal and communication skills necessary in industry. Equally important, they become aware that design is not a unique solution—rather, there are many acceptable designs for a single system.

The Proposed Concept:

Presented herein is a new curriculum for the civil engineering program at Western Michigan University that:

- Is based upon the evolving engineering office of the 21st century,
- Utilizes modern technology and computational tools from the onset of the educational process,
- Utilizes student teams and project work throughout the entire educational process, and
- Stresses oral, graphical, and written communication, and team skills.

An integral part of this curriculum is a freshman experience that stimulates the interest of first-year students and prepares them for success in studying engineering. There are a number of model freshman engineering programs in the U.S. These have replaced "traditional" freshman engineering courses that focus *only on career exploration*. Instead, the new programs have identified the following elements as necessary to successful retention of first-year engineering students[2,3,4,5]:

- Connection between mathematics, science, and engineering concepts;

- Building teamwork, communication, and problem-solving skills;
- Introduction to the engineering design process including completion of a design project; and
- Career exploration and choices.

Furthermore, the newly developed undergraduate civil engineering program will provide a nearly seamless integration of undergraduate and graduate education that enables students to obtain a design-oriented master's degree with one additional year of study beyond the baccalaureate degree.

The College of Engineering and Applied Science at Western Michigan University envisages that this program will become the model program for other programs in the college. The newly developed curriculum, including the freshman engineering program, will be pilot tested in Civil Engineering when that program officially begins in August 2003. The civil engineering program at WMU is an ideal place to implement the new curriculum because the civil engineering program is just being initiated. There are no students in existing curricula and legacies that must be accommodated. Ultimately, the concepts that are developed and demonstrated in civil engineering will be transferred to other well-established engineering and engineering technology programs in the college. Hopefully, the program developed will serve as a model for programs throughout the region and ultimately the nation.

When developing a new program, however, one must be cognizant that there is not complete freedom to restructure all courses, as students outside the engineering program and the college take many of the courses. These courses include the sciences and mathematics, as well as fundamental engineering courses taken by several disciplines.

The Student in the Classroom

As we begin to address revamping an engineering curriculum, we need first to look at the student entering engineering programs. The students being taught today have grown up wholly in the electronic age. These young people have been called e-kids and the e-generation. On MSNBC[6] "The Site" today's students were referred to as cyber-children—children who have been raised completely in an age of interactive graphics, in an age of interactive technology. The teaching methods used to educate these students must change to accommodate the environment in which they were raised. The methods by which we engineering faculty learned are not necessarily the methods that will enable students today to learn. The question, then, is how can students be motivated to achieve knowledge and comprehension of engineering subject matter and be able to apply and analyze that knowledge[7]. Stated differently, the question is: "How do we take them from where they are now to where we need them to be?" Two developments have occurred in recent years that dramatically affect the means through which students learn—the means through which they are transformed into knowledgeable engineers. The first of these is educational technology—modern computational technology with its rich capability for visual representation[8]. Today's students grow up in a society that depends heavily on television and multimedia for information. They have learned to learn by visualization, with less emphasis on learning by listening and reading. To a great extent, though, the visualizations used are visualizations prepared by others—the student is not an active participant in the process[7]. The second development that should affect the manner in which students are taught is a better understanding of how learning occurs. In the past 20 years cognitive psychologists have advanced significantly the understanding of how students perceive, process, store and retrieve information[9, 10, 11]. These understandings have led to a new learning paradigm where the instructor's emphasis should be on the learner's capacity to effectively process information presented through different sense modalities. This change should lead to dramatic alterations of the instructor's role as was previously suggested[7]. Emphasis on the capacity to process information should also affect the manner in which information is presented to the students and the exercises they are expected to perform.

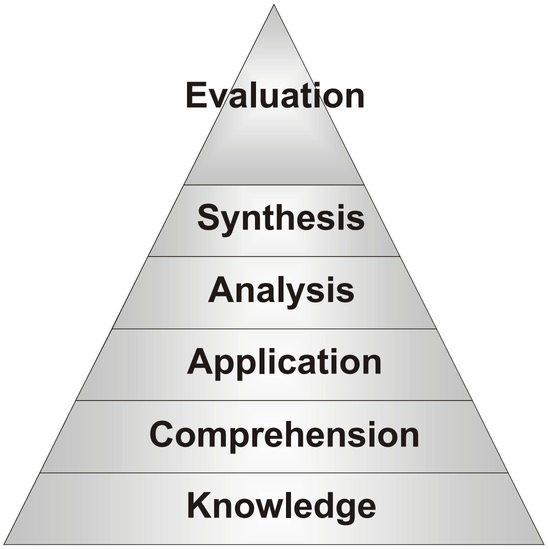

Figure 1. Taxonomy of the Cognitive Process[12, 13]

The process of engineering education is a cognitive process. Cognitive behaviors involve the recall of specific information, the application of that information, and the processes of analysis and decision making[14]. A taxonomy of the cognitive process is shown in Figure 1. Knowledge requires the ability to recall that which has been communicated whereas comprehension requires an understanding of that which has been communicated. Application requires the use of abstract concepts in specific situations and analysis requires a dissection of that which has been communicated. Synthesis and evaluation, respectively, require the organization of a pattern from the separate parts and judgment of the subject against a standard of appraisal[15]. During his or her engineering education, a student should probably be able to grow to the fourth level of the cognitive process. The student should be able to dissect the information that has been presented in the classroom and be able to apply that information to new problems in the design office. The last two levels likely will come through the professional maturation that comes with experience.

Stages of Engineering Education

A discussion of the different stages of engineering education must begin with a discussion of what is engineering education, in particular, what the difference is between engineering education and engineering technology education. In recent years, the distinction between engineers and engineering technologists has become very blurred. Understanding this distinction, however, is important when redesigning an engineering curriculum so that a proper focus can be maintained and a proper utilization of technologies is maintained.

Simply stated, engineering and engineering technology can be described as follows:

- **Engineers** have a broad understanding of the fundamental principles that can be applied to the conceptualization and design of new and innovative systems. Furthermore, engineers have an understanding of the impact of design options on the performance of the entire system.
- **Engineering Technicians** apply engineering principles to the routine design of components in a system conceptualized by an engineer—the focus is on the application of established design principles developed by engineers.

The curriculum proposed herein is for the development of engineers. As such, that program of study must provide the student with the ability to understand the issues related to the design of systems as well as the design of components.

When discussing development of an engineering program, one must also be very cognizant of the requirements for professional registration. At present, most states permit registration as a Professional Engineer after graduation from a program of study accredited by the Accreditation Board for Engineering and Technology (ABET), having accumulated four years of professional of experience, and having successfully completed registration examinations. In recent years, there has been considerable discussion about the Master's degree being the first professional degree—the degree that would be required to become a Registered Professional Engineer. The American Society of Civil Engineers is one of the lead organizations pushing for this requirement. In Policy Statement 465, ASCE[1] states that:

> *The American Society of Civil Engineers (ASCE) supports the concept of the Master's degree or Equivalent as a prerequisite for licensure and the practice of civil engineering at a professional level.*
>
> *ASCE encourages institutions of higher education, governmental units, employers, civil engineers, and other appropriate organizations to endorse, support, and promote the concept of mandatory post-baccalaureate education for the practice of civil engineering at a professional level. The implementation of this effort should occur through establishing appropriate curricula in the formal education experience, appropriate recognition and compensation in the workplace, and congruent standards for licensure*

Even if this proposed requirement does not come into force, it strongly indicates the need for advanced education of engineers. Nevertheless, a curriculum must be responsive to the possibility for such a requirement, and graduates of the program must be able to comply with the requirement. Further, given the myriad of constraints that exist in undergraduate programs that are beyond the control of the faculty, it is still necessary that engineering programs provide for education beyond the degree program itself. A critical part of this mandate is to accommodate a seamless integration of the bachelor's degree and a professional master's degree.

Therefore, the five stages of development envisaged for an engineering program for the 21st century are as follows:

- **Learning the Tools**: The student develops an understanding of the fundamental mathematical and physical sciences that underpin engineering education and has an introduction to engineering calculation, including use of computational software. The student begins the process of engineering problem solving and of engineering thinking.
- **Developing the fundamentals**: The student develops a solid understanding of the fundamental principles of engineering science and is able to apply those principles, along with principles of mathematics and physical sciences, to the solution of elementary engineering problems. Coursework would include study in the areas of basic mechanics, thermodynamics, electric circuits, and engineering experimentation. The fundamentals learned in these courses, along with principles of mathematics and science, are used as a first approach to engineering analysis and design.
- **Learning to conceptualize and design**: The student will learn about design codes and specifications, will learn the principles of engineering analysis, and will learn fundamental concepts of engineering design at the component level. By the end of this phase of study, the student will be able to design components in systems and will understand the relationship between engineering analysis and design.
- **Transitioning to Practice**: In this stage of study, the student learns to formulate the design of an engineering system from a set of stated criteria, be able to identify the steps necessary for the implementation of that design, and have a fundamental understanding of the impact of design decisions. Coursework includes engineering design with particular emphasis on the principles of system design. In most traditional undergraduate engineering programs, this is the stage at which baccalaureate programs end.
- **Becoming a Professional**: The student pursues advanced, theoretically based, discipline-specific analysis and design topics with particular emphasis on the understanding of system behavior. In this stage, the student develops a solid understanding of the relationship between analysis and design, develops the ability to assess system performance, and understands the impact of design decisions on system behavior.

The topical content, desired outcomes and technology to be utilized in each of these phases are indicated in Table 1 at the end of this narrative.

Guiding Principles of the New Curriculum

The curriculum for the new engineering program for the Department of Civil and Construction Engineering was based on the principles and concepts discussed heretofore. The guiding principles for this curriculum were to:

- Build a new curriculum modeled on the engineering office of the 21st century. The curriculum will stress teamwork (including the ability to work effectively with other disciplines) and oral, graphical, and written communication skills. Engineering analysis and design will be examined at the system level.
- Use the most current tools and technologies for modeling and analysis.
- Incorporate modern educational methods in the learning process so that faculty become conversant with student learning styles and teaching methods.

- Use classrooms within the civil engineering program configured for effective teaching in lecture format as well as team interaction during the same class period.
- Satisfy the requirements of ABET for professional accreditation.

The curriculum developed likely will view the development of an engineer as a multi-year process—course sequences that flow from one to another and that cross engineering and other technical disciplines—rather than conveyance of knowledge in discrete courses. Full implementation of the curriculum is expected to take about three years. Some characteristics of the newly developed program include:

- Civil engineering courses will be taught in a team environment in purpose-built classrooms.
- Use of computational tools will be integrated throughout the curriculum.
- There will be a focus on multiple acceptable solutions to the design problems.
- Engineering ethics and professional responsibility will be stressed throughout the educational process.

Curriculum Development

Presented in Chart 1 is the flowchart for the curriculum that has been developed. Of necessity, because of traditional University structure, the curriculum is still composed of individual courses. This curriculum was built on the ABET accredited construction engineering that exists in the department; the department now offers undergraduate degrees in both civil engineering and construction engineering, and plans to continue doing so. One must look below the surface to observe the impact of the guiding principles on the resulting curriculum. Throughout all courses, team projects and the design process are an expected part of the course content.

The Freshman Sequence. The freshman introduction to civil and construction engineering is contained in a two course sequence. This intent of this sequence is to satisfy the needs for a freshman experience identified above. The first of this sequence presents a broad picture of civil engineering, begins the process of thinking through engineering problems they experience daily, and introduces tools for engineering computation. These tools include spreadsheets and MathCAD. The curriculum does not include a computer science programming course because the concepts of solution logic, including looping and decision-making, can be taught effectively in MathCAD, and it is a tool that can be used effectively in all subsequent engineering courses.

The second part of the freshman engineering sequence is Civil Engineering Measurement. This course continues the introduction to civil engineering through laboratory measurement of phenomena associated with the different areas of civil engineering. To the greatest extent possible, the laboratory exercises will deal physically with phenomena addressed in later courses on a theoretical basis, such as stress measurement and fluid flow. This course also provides basic instruction in electronic circuits, data acquisition including sensor selection, laboratory procedures, analysis and reporting of experimental data, and experimental design. The laboratory and lecture are integrated—there are not laboratory sessions separate from lecture. On all experiments, the students will work as teams of two to four students—the size of the team depends upon the topic. Because of the course content, this course serves as the foundation for all laboratories taught in the curriculum.

Although not strictly a part of the freshman sequence, Engineering Graphics is a part of the freshman experience and taught by the department for civil engineers. Teaching the course within the department, and separate from normally offered engineering graphics courses, students learn about the types of projects dealt with by civil engineers and the develop the ability to present graphically design in the broad context of civil engineering. Students will prepare drawings of highway geometry, building layout and structural details, topographic maps, and utility systems. CAD is a dominant part of the course content.

Big—Small—Big Picture. This part of the curriculum is designed to provide the students with a broad overview of civil engineering systems, then to address design of individual components, and then move back to the big picture. This will be accomplished through the codes and specifications course, the usual design courses, and capstone design. In the codes and specifications course, students learn about the various design codes applicable to civil engineering projects—IBC, AREA, and AASHTO to name a few—and the application of these code to global design requirements. The intent is not to delve into the requirements for design but rather study the requirements for systems. For example, students would study the global requirements for an office building constructed of steel, but not the requirements for designing beams and columns with the building. This latter topic is discussed in latter design courses. The loop is then closed in senior design when teams of students design a system.

With the structural design sequence, the course Introduction to Structural Design contains instruction in both steel and concrete design. This course provides all students in the department, civil engineers and construction engineers alike, fundamental education in design with both materials. Through technical electives, students in civil engineering can select from advanced design courses in both materials. By configuring the structural design sequence in this manner, construction engineers receive education in both materials, which heretofore they did not, and the civil engineers have a greater number of elective courses in the curriculum without increasing credit hours and without sacrificing fundamental knowledge.

In the capstone design course, teams of students work on the same project. Through the presentations that follow, the students then observe different approaches to design of a system, and can begin to develop judgment regarding strengths and weaknesses of different approaches.

The Fifth-Year. As previously discussed, a graduate degree is becoming almost a necessity for students entering professional practice. This concept is proposed and supported by ASCE for all civil engineers. As such, one of the design objectives of the curriculum was to create an undergraduate program that can seamlessly mesh with a fifth year of academic study during which time the students can earn a master's degree, but without requiring a fifth year for completion of the undergraduate program. To accomplish this, the faculty decided to:

- Maintain three dominant focus areas within the department, while providing breadth and depth necessary for ABET accreditation. These focus areas are structural engineering, construction engineering, and transportation engineering.

- Require student to pursue one of two possible tracks in the “fifth year” master’s program. These tracks would be structural/construction engineering or transportation/construction engineering.
- Require a core curriculum in the graduate program that includes one course from each of the three focus areas in the department.
- Maintain a “research-based” graduate program for students wishing to pursue research and further graduate study in addition to the professional-practice oriented “fifth-year” program.

Given this design objective, and the work done at the undergraduate level, the graduate program is currently under development. That program is intended to flow naturally from the undergraduate program. Its success and implementation will be reported later.

Required Department Support

To make this curriculum, and in particular to make the design and team projects work, there must be departmental focus for these activities—specifically, these activities must be a part of the program objectives required as part of the ABET assessment plan. Furthermore, these activities and the ABET program objectives must be supported by the departmental strategic plan. In essence, the faculty and the department must be accountable to each other for the success of the program. Within the civil and construction engineering department at Western Michigan University, the following ABET program objective, and the related outcome and metrics, commit the department to this plan:

> *Program Objective*: Graduates can design systems, components, and processes and can recognize the strengths and weaknesses of the design. (ABET Criteria C)
>
> > Program Outcome: Graduates successfully complete design projects, individually and in teams, integrated throughout the curriculum.
> >
> > - Metric: At least 90% of all civil engineering courses include at least one team design project and one individual design project
> > - Metric: All upper division civil engineering courses include at least one team design project and one individual design project
> > - Metric: All students earn a grade of at least C on design projects

The strategic objectives, and the related measures and metrics, from the departmental strategic plan supporting this particular ABET program objective are:

> *Objective*: Offer exceptional educational experiences through a strong, innovative curriculum that fosters creativity and team work.
>
> > Measure: Courses with team projects
> >
> > - Target: At least 95% of all civil and construction engineering courses have at lease one team project or assignment.

- Target: At least 75% of all civil and construction engineering courses have two or more team projects and assignments.

Objective: Develop an excellent state-of-the-art educational environment

Measure: Educational technology infrastructure

- Target: By 2003, develop a plan for improving equipment in all teaching laboratories and integrating computer-based measurements into the teaching laboratories.
- Target: By 2006, all teaching laboratories upgraded to meet plan.

A piece of the technology infrastructure is a project laboratory configured for and conducive to work on team projects. These program outcomes and strategic objective hold the department and the faculty for achieving the goals of the curriculum. They will be assessed annually and progress in that regard can be tracked.

Conclusions and Observations

The curriculum presented in this paper has been implemented for the new civil engineering program. The first students, mostly transfer students are entering the program with expected graduation by spring 2005. The entire faculty participated in the development of the curriculum and feel ownership in it. Thus, making the changes in the syllabi for courses that already exist and adding necessary new courses to those available have not been an issue.

When developing this curriculum, the department had two advantages not common to all programs. First, this is a new civil engineering curriculum. Consequently, there are no legacies that must be accommodated—the slate was truly clean. Second, the faculty developing the curriculum was very small and had a widely varying background crossing both discipline and national boundaries.

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Biographical Sketches

OSAMA ABUDAYYEH is an Associate Professor of Construction Engineering and Management. He is the director of the current undergraduate and graduate programs in construction engineering and management. Dr. Abudayyeh led the development of the ABET self-study report for the construction engineering program at WMU. He also serves as the secretaries of the ASCE Construction Engineering Education Committee, charged with developing ABET accreditation criteria for construction engineering programs. Dr. Abudayyeh attended numerous workshops dealing with engineering process education, curriculum design, and program assessment.

JAMES K. NELSON is Professor and Chair of Civil and Construction Engineering at Western Michigan University and was previously chair of civil engineering at Clemson University. Previously he served as Program Director of the Clemson University Graduate Engineering Programs at The Citadel in Charleston, SC. At Clemson, he was one of the pioneers in dissemination of course material in distance education programs via the Internet. Dr. Nelson has co-authored an undergraduate structural analysis and a undergraduate steel design textbook, and has developed software for three structural analysis and design textbooks.

EDMUND TSANG is an Associate Professor of Mechanical and Aeronautical Engineering and Associate Dean for Undergraduate Programs and Assessment in the College of Engineering and Applied Science at Western Michigan University. His principal responsibilities are undergraduate programs, college assessment activities, and engineering pedagogy. He also manages the college's accreditation efforts and faculty professional development activities in engineering pedagogy. He is director of the Center for Excellence in Engineering Education, and has a number of funded and pending grants in engineering education and outreach to K-12 students.

MOLLY W. WILLIAMS is a Professor of Mechanical and Aeronautical Engineering, and Associate Dean for Research and Graduate Programs in the College of Engineering and Applied Sciences. She has taught courses in thermal-fluid sciences, engineering mechanics, instrumentation, and materials science. College responsibilities include college curriculum and program assessment issues at both the graduate and undergraduate levels, including program accreditation efforts from 1989 through 2001.

Table 1. Characteristics of the Five Phases of Engineering Educational Development

Educational Phase	*General Topical Content*	*General Expected Outcomes*	*Technology Utilized*
Learning the Tools	Mathematics Physical Sciences Computational Tools Engineering Design Graphics	The student has an understanding of the fundamental mathematical and physical sciences that underpin engineering education and an introduction to engineering calculation	Computational software Engineering graphics software
Developing the Fundamentals	Engineering Mechanics Mechanics of Material Behavior Engineering Measurement Experiment Design and Reporting Data Collection and Interpretation	Obtain a solid understanding of the fundamental principles of engineering science and be able to apply these principles, along with principles of mathematics and physical sciences, to the solution of elementary engineering problems	Computational software Data acquisition software
Learning to Conceptualize and Design	Design codes and Specifications Engineering Analysis Introduction to Engineering Design	The student will be able to perform component design and understand the relationship between engineering analysis and design.	Computational software Engineering Graphics Software Data acquisition software
Transition to Practice	Engineering Design with Particular Emphasis on Principles of System Design	The student will be able formulate the design of an engineering system from a set of stated criteria, be able to identify the steps necessary for the implementation of that design, and have a fundamental understanding of the impact of design decisions.	Computational software Engineering graphics software Data acquisition software
Becoming a Professional	Advanced, theoretical based, discipline-specific analysis and design with special emphasis on system behavior.	The student has a solid understanding of the relationship of analysis and design, has the ability to assess system performance, and understands the impact of design decisions on system behavior.	Computational software Engineering graphics software Data acquisition software Advanced analysis software

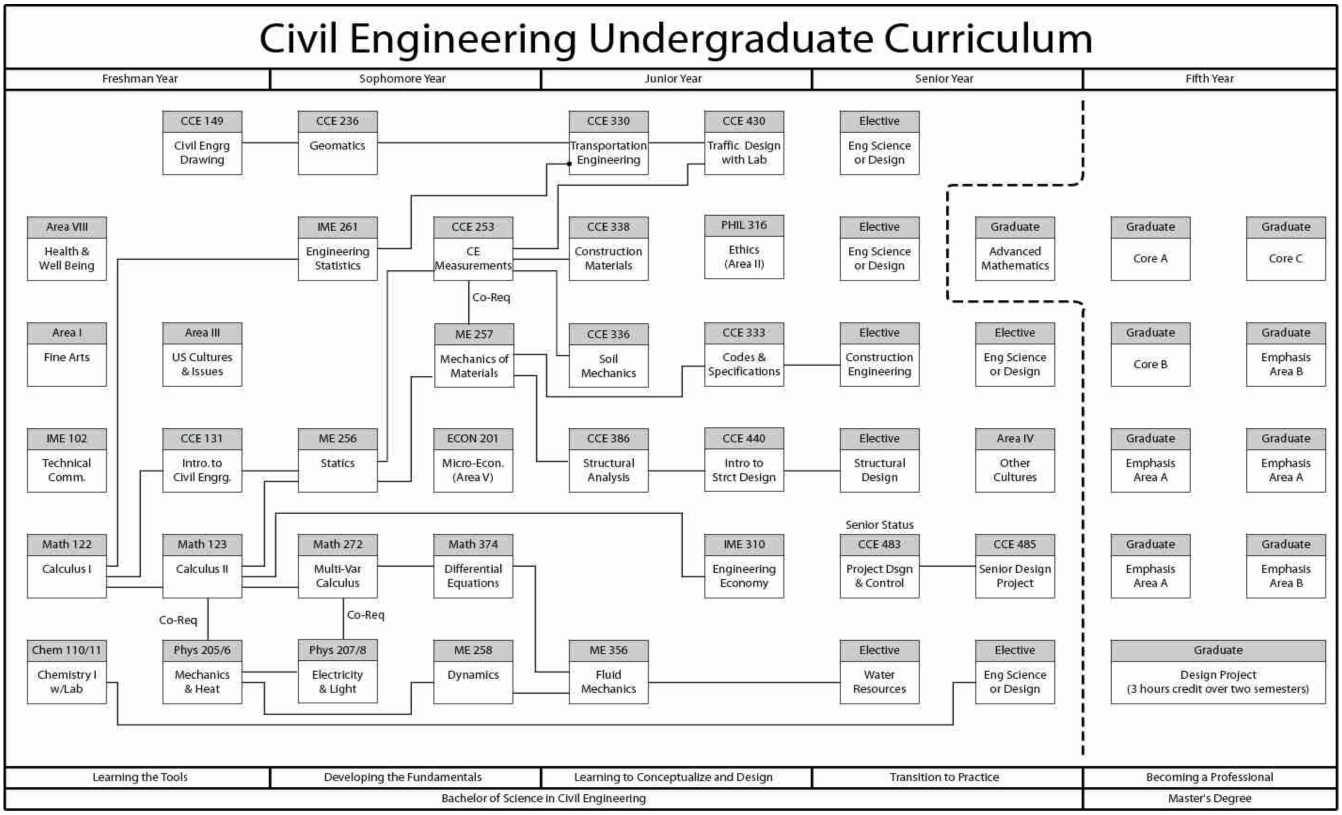

Chart 1. The civil engineering curriculum