A Project-Based Integrated Curriculum for Civil Engineers

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Abstract — *Changes in the needs of society and developments in computer science and information technology are changing the role of civil engineers and are opening a series of exciting challenges and opportunities. Computer technology has liberated ci vil engineers from the tedious task of time performing complicated, but routine computations, allowing them to concentrate on the more creative part of the design process, to integrate design and construction (or manufacturing), and to consider explicitly the economic and social implications of their work. At the same time the question is no longer how a system behaves under specified actions but how it can be designed to behave in a desired way; in other words, how to control the performance of the built e nvironment. The future focus for civil engineers will be on designing, repairing, maintaining, protecting and preserving the built environment based on ensuring system performance during demand actions with varying probability of occurrences. As a result , the Civil Engineering Department at Texas A&M University is planning a comprehensive revision of the philosophy and practice of undergraduate civil engineering education. A new curriculum is proposed built on a project -to-theme-to-topics model in which students are first presented with actual projects every academic year starting from the freshman level. A series of courses provide a central focus and structure for the curriculum with student teams addressing projects that cut across disciplines within civil engineering. The teams working on these projects would be guided to decompose a project into themes, such as dynamic analysis, environmental impact, geotechnical analysis, etc. so that they learn how engineering thoroughly breaks down large complex problems into conceptually manageable and interacting components. Then, students would use more traditional topics as analysis tools to generate quantitative analysis of the thematic issues. As the students are led to discover the knowledge needed to sol ve the problems arising from their projects, explicit links to specific subject courses in the curriculum will be made. Courses on individual subjects throughout the curriculum are then linked through the common context provided through the project sequen ce. The class material and presentation will be problem and project driven, incorporating just -in-time learning with a practical motivation for learning the needed skills. The project -theme-topic model will refocus attention of students and faculty away from the lowest two levels of Bloom's Taxonomy (knowledge, comprehensive) and toward the higher levels (application, analysis, evaluation, synthesis) that are expected and demanded of engineering graduates.*

Index Terms — *civil engineering, curriculum, int egration , problem -based learning .*

INTRODUCTION

The many education conferences, workshops, and sessions on engineering education that have taken place over the last two or three decades seem to indicate some degree of dissatisfaction with the way we are educating civil engineers. The advances in computation and information technologies have affected significantly the role that civil engineers will play in the future. As a result, the material they should be learning must also change. Yet in most universities the curriculum has changed little over this period of time, with only piecewise modifications to some specific courses, and without a comprehensive redesign of the overall process. It has been said by some that universities do a good job at teaching basic science and engineering fundamentals (particularly theory) but not at forming true engineers, a statement that is not without merit. Many engineering schools have made significant changes in their undergraduate programs—on their own, or with the help of NSF and other grants. Some of these "paradigm-shifting" engineering schools include the Massachusetts Institute of Technology, Harvey Mudd College, the Colorado School of Mines, Worcester Polytechnic Institute, Drexel University, Texas A&M University, Rose-Hulman Institute of Technology, Columbia University, and the University of Colorado at Boulder [3-4].

Most integrated curricula are based on the observation that a certain body of knowledge is common to a number of different courses and they aim at distributing the content over a these courses rather than packaging it into a new "parcel". One example of this is the (laudable) attempt to introduce more writing intensive courses in the traditional civil engineering curriculum, in order to place more emphasis on communication skills. A different approach is to link content that has been separated by providing cross-references. A typical case is the introduction of engineering based problems and examples in the traditional math and physics courses. The main shortcoming of these approaches is practical rather than theoretical: they require large amount of cooperation and collaboration, which is sometimes difficult to obtain within the current structure of our departments. Even when the will exists, the frequent rotation of instructors creates obstacles to the implementation and the long term stability of the solution scheme. In order to be successful, a new approach to the curriculum must bring innovation while adjusting the pace so that it is always just above the ability of the department to change.

The revised curriculum proposes to integrate the motivation for certain knowledge, rather than the knowledge itself. It starts from the existing courses and provides a unifying framework in which these courses can be linked from the outside. This paper describes how this approach was developed and the initial framework for the vertical integration present in the revised curriculum.

THE DESIGN PROCESS

Identifying the Problem

During a recent visit by the department's advisory board, several common themes began emerging from focused discussions within specialty areas. Based on that feedback, a committee of approximately 15 faculty members met to discuss the strengths and weaknesses of the current curriculum offered by the Department of Civil Engineering at Texas A&M University. Through several discussions, several issues were identified as critical to be addressed. The first major issue identified that students cannot make connections between material learned in different topics as well as to the profession & changes in civil engineering profession.

When they start college, most students know civil engineering deals with constructing buildings and other large structures. Their experience is limited to the structures they have experience with in their local communities and they often have a very superficial grasp of what civil engineering really is and what it entices. Their understanding of "building" is still the same as when they played with Lego blocks as kids. Their expectations for their college career are that they will learn "how to build", but most of them would have difficulty in qualifying the profession of the civil engineer beyond those words. Since they do not know what civil engineering really is, it is very confusing and frustrating to them that all they are required to work on in the first year and a half of their college career is math and science and seems hardly related with civil engineering.

Those freshmen who elected civil engineering as a major spend the first year and a half of their college career on subjects that, to them, are unrelated to what they wanted to study. Since their understanding of the civil engineering profession is incomplete and very shallow, they feel betrayed and choose to transfer to a different discipline, for which perhaps they have developed a better understanding, or abandon engineering altogether. We often hear our students complain that engineering is too difficult, and the first courses are "weed out" classes, not necessary for the chosen profession, just to ensure that the number of the elects is kept small. The calculus, physics, chemistry classes are more of an initiation rite to them, than the basis for their future professional career. On the other hand, any engineering professor would be quite horrified at the thought of graduating students who do not know differential equations or mechanics.

In the later courses, at the junior and senior level, the instructors often will provide occasions for the students to use the knowledge accumulated in the previous years. The motivation, though, comes too late, when some students have already left the field and others have already settled in the habit of keeping each subject in its separate compartment. It is also quite unfair to the students to expect them to be able to draw parallels and connections among the subjects they are studying while they are learning them. It took the experts a lot of time and thinking to be able to navigate the material so effortlessly. We need to provide our students with the tools to get them started on this path. The proposed series of courses would provide motivation through the first years and help the students reach a better understanding of civil engineering since the beginning. The motivational aspect is prevalent in the freshman year and is still important in the sophomore year.

A second major issue to be addressed was that the changes in the engineering profession that were not incorporated in the traditional curriculum. Owing to current advances in computer software and the development of new technologies, such as sensors, new and composite materials, and intelligent control systems, civil engineering design can no longer be based on traditional analysis approaches. The design process must now focus on the Control of the Built Environment. The civil engineering curriculum must be changed to train engineers to think at a higher level and with a broader scope to reflect the new design paradigm.

Additionally, the group reached the agreement that the existing "infrastructure" should be changed through a slow progression coming from within rather than imposed from the outside. Realistically, any organization is somewhat resistant to changes because of the inherent inertia. In the case of academia the resistance comes from the faculty as well as the students. In order to be effective, a new approach to the curriculum must be embraced by both groups. The revised curriculum begins with building an overarching structure of courses which provide motivation and context for the traditional content using innovative content and pedagogy. At the same time, faculty development is also a priority. This approach is non-threatening to the existing system, but introduces new elements and encourages change by providing examples and tools for immediate use. The problem of resistance to change has been identified by other authors [1-2] as one of the major obstacles to the implementation of an integrated curriculum.

Resulting Objectives for Revised Curriculum:
As our department is very large, with nearly 60 faculty members and approximately 850 undergraduate students, it was imperative that everyone involved in revising the curriculum agreed on the common objectives for the program. After several meetings and discussions, the following list was identified as the key objectives for the program.

- Implement faculty professional development to support pedagogical changes.
- Adapt and create a vertically aligned series of project-based, case-study seminar courses to serve as the integration focus of other core civil engineering courses.
- Create connections between vertically aligned core courses and other foundation courses at each level.
- Selective pruning: Examine course contents to remove unnecessary legacy materials allowing for introduction of emerging knowledge and technologies, as well as deeper understanding of fundamental concepts.

PROPOSED INTEGRATED CURRICULUM

The new curriculum will be built on a project-to-theme-to-topics model in which students are first presented with actual projects selected with the help industry partners, and advancing through courses that support the application of engineering in a project-based setting. The Foundation Coalition's success in establishing team-based collaborative learning methodologies, proved to enhance the retention and transfer of knowledge, will guide the way these courses are structured. The basic structure of the revised curriculum is analogous to a tree form, with the central series of project-based courses providing the supporting structure, or trunk, shown as the circled courses in the figure attached. These courses build upon the knowledge and experiences of the foundation courses, such as math and physics, both in terms of course content as well as educational experience. Additionally, they will provide a central focus and structure for the curriculum with student teams addressing projects that cut across disciplines within civil engineering. The Tree figure is a visual representation of vertical course alignment of the proposed core civil engineering curriculum. The first (107), second (207) and third (307) year targeted courses will be developed or adapted via this project with the required degree courses and specialty courses being aligned horizontally. The teams working on these projects would be guided to decompose a project into themes, such as dynamic analysis, environmental impact, geotechnical analysis, etc. so that they learn how engineering thoroughly breaks down large complex problems into conceptually manageable and interacting components. Then, students would use more traditional topics as analysis tools to generate quantitative analysis of the thematic issues. As the students are led to discover the knowledge needed to solve the problems arising from their projects, explicit links to specific subject courses in the curriculum will be made.

Several common themes/strategies are present in all four courses. These include, in addition to the project driven approach, an emphasis on developing communication skills, industry collaboration, development of visualization skills, and exposure and utilization of new and emerging technologies. Courses on individual subjects throughout the curriculum are then linked through the common context provided through the project sequence. Individual courses that are required by all students are shown as boxes on the curriculum tree, while the courses in diamonds are taken by most though not all students. At the junior level, individual courses are available in different specialty areas within civil engineering. They provide a possible specialization path within the broad field of civil engineering, branching out from the common core. Courses at this level investigate system behavior and provide students with analysis skills. Course material and presentation will be problem and project driven, incorporating just-in-time learning with a practical motivation for learning the needed skills.

At the senior level, the goal changes from one of analysis to that of performance-based engineering. Instead of asking our students "How does this system behave during a demand action", the question of interest becomes "How can we design this system to control its performance during a demand action?" Discipline specific courses, such as steel or concrete design, provide a preliminary introduction to the design process of system components, while the capstone design course utilizes an open-ended performance-based engineering methodology for the system.

A series of one credit hour courses will be developed to introduce the concepts and methods of civil engineering beginning in the first year. These courses will provide the central focus and structure for the curriculum with student teams addressing projects that cut across specialty areas within civil engineering. The courses are motivated by two main needs: (1) the observation that the students struggle in the process of internalizing knowledge from the information they accumulate during their path through higher education, and (2) students' failure to perceive the curriculum as a whole and the different courses as inter-related elements of a coherent system of knowledge.

Several common themes/strategies are common to all four courses. These include: (1) integrating design throughout the curriculum through the use of a project driven approach, (2) an emphasis on developing communication skills, (3) industry collaboration, (4) development of visualization skills, and (5) exposure and utilization of new and emerging technologies. A description of the individual courses is given in the following sections.

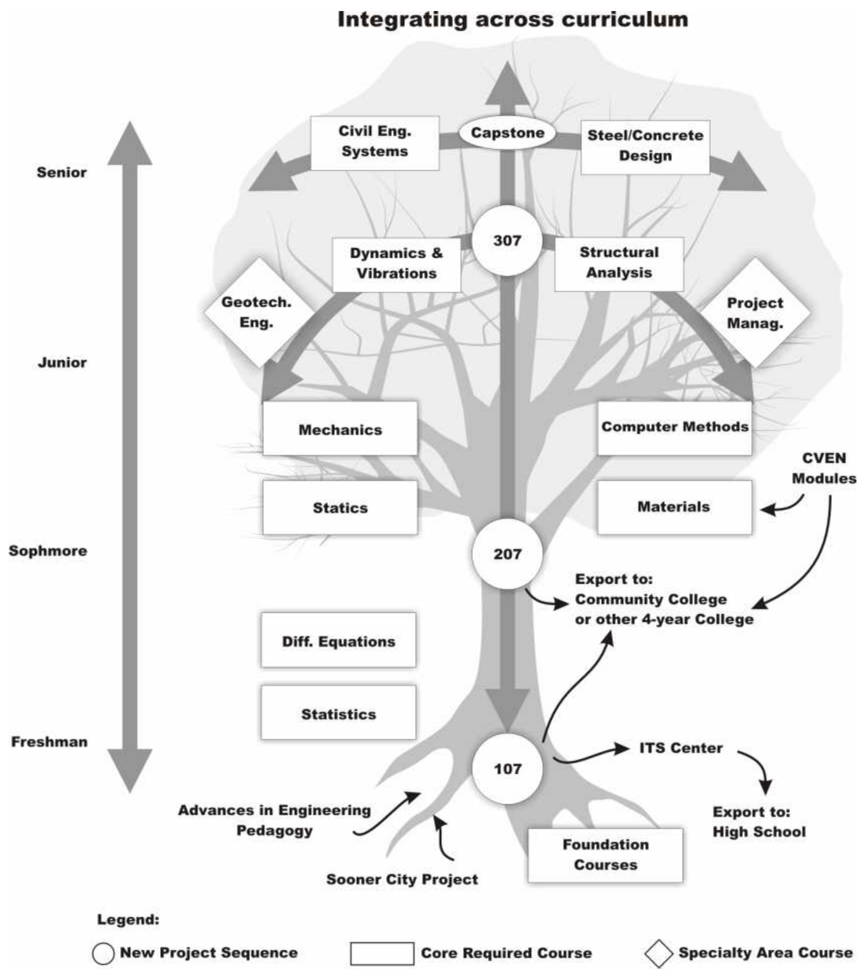

FIGURE 1
VERTICAL AND HORIZONTAL CURRICULUM INTEGRATION.

First Year Course (CVEN 107) – Introduction to Civil Engineering

First year civil engineering majors spend the first part of their college career on subjects (i.e., Calculus, Physics) that, to them, are unrelated to what they wanted to study. Since their understanding of the civil engineering profession is incomplete and very shallow, they often transfer out of engineering far before they reach the courses that offer opportunities for engineering applications. Students often complain that engineering is too difficult, and the first courses are "weed out" courses, not part of their chosen major. The calculus, physics, and chemistry courses are more of an initiation rite to them, and students have already left or become trained to keep each subject in its separate compartment prior to accessing application courses.

CVEN 107 presents the profession of the civil engineer and will be open to all students, irrespective of their major. The purpose of the course will be to "hook" the students by showing them cutting edge civil engineering projects and developing excitement for the field of civil engineering. Non civil engineering or undecided students who may be interested in changing majors can use this course as a way to explore a different career. The current introductory seminar course is required in the second year and consists of power point presentations on the different sub-disciplines of civil engineering, plus a few lectures on writing and communication skills, ethics, and graduate school. The new course will be moved to the 1st year to provide students with immediate introduction to the field and motivation to remain a civil engineering major.

The new first-year seminar will have integrated presentations on a number of large, exciting, cutting edge projects incorporating two or three different sub-disciplines. Industry representatives will be invited to speak to the class regarding the challenges the project presented to their discipline. Each project will constitute a module for two or more classes, including presentations and teamwork activities. Each module will require the completion of an assignment intended to build communication skills, whether written, visual, or oral. The modular nature of the course will allow for ease of exporting it to other colleges and universities, as well as high schools. Individual modules can be used independently at the high school level to improve understanding of civil engineering careers.

Projects will be chosen in such a way that the interplay of the different areas of civil engineering will be highlighted and additional important topics, such as ethics, will also be addressed. Elements tying great civil engineering accomplishments of the past to the use of the basic math, science, communication, and graphics tools and skills the students are acquiring through the institutionalized FC program will be incorporated. For example, if excessive settlement is the problem, a load-displacement curve for one sample of soil could be shown and the total settlement related to the integration along the vertical axis. The course will also present the challenges at the frontier of civil engineering, especially emerging technologies being developed to address modern challenges such as advanced sensing technologies to measure behavior or development of new materials, such as composites.

Second Year Course (CVEN 207): Elements of Civil Engineering

The second course in the sequence will be geared towards building the vocabulary of the civil engineering discipline and focuses more on broad categories of projects. Whereas in the bridge on the Messina Strait and the Petronas Towers will be presented in 107; 207 will consider bridge engineering and structural systems for buildings. A major goal of this course is to expose students to the process of project decomposition. They will examine the many parts that contribute to a project, from the actual physical elements such as materials, equipment, and local environment to the people, concepts, and regulations involved. Emphasis will be given to the broader technical issues such as: safe/unsafe, acceptable deformations, risk/reliability, environmental impact, constructability. Students will be exposed to the behavior of civil engineering systems from a conceptual, rather than theoretical or analytical, perspective.

Each type of civil engineering project will be characterized based on the interplay of the different traditional disciplines, with an approach similar to that used in presenting the mega-projects in the first course. Again, practitioners will be in the class to illustrate how the specific tasks are integrated in the whole in the practice of civil engineering. Each issue will be discussed in the context of the knowledge required to successfully address it, making explicit connections to the material being taught at the second year level such as statistics, statics, dynamics, and materials.

One of the fundamental goals of this course is encouraging students to develop the skills needed for life-long learning. Coursework will include developing questions and researching answers by collecting information on different projects from different sources such as the library (magazines, journals, reports, building codes) or the web. Assignments will be structured as sections of a final report in different formats, such as a traditional paper booklet, a web site, a navigable document, a power point presentation, or a movie. One of the major problems students face in writing is organizing the material in a logical, coherent, and compelling manner. By moving away from the traditional "paper" report that assumes sequential reading, alternative presentation formats require a greater effort in synthesis and consequently focus more attention on the structure and logic of the document.

Junior Course (CVEN 307): Concepts in Civil Engineering

By the third course in the sequence, students have completed the basic math, science, and engineering part of the curriculum and are getting acquainted with the basics of civil engineering, such as mechanics of materials, numerical methods, fluid mechanics, and structural analysis, where exact analytical tools are developed. Faculty for these courses will be able to refer to and expand on the concepts explored in the second year course. At the same time, the course will provide a context for the engineering project course at the junior level.

The main goal of this course is to introduce the concepts of design as a creative process based on trial and error procedures and an exploration of alternatives. Current courses often focus on either analysis or design, and the connection between the two is left to student discretion. This course will provide them with the missing link between those activities. Both the special projects of the first year and the typological projects of the second year will be revisited. The students will be asked to experiment with the basic concepts of civil engineering and develop a more intuitive understanding of their relevance in the context of a project. The integration of the different sub-disciplines will also be more explicit as students begin to actually experience the different branches, or specialty courses, of civil engineering.

In this course students will explore the deep meaning of their idea that "civil engineers build structures". As they develop their ability to perform analyses in the third year courses, this course will encourage them to discover the importance of analysis and its limitations. In their professional practice, civil engineers are not given a conceptual rendering of the problem to analyze; they are given the much more complex task of deciding the best way to accomplish the goals required by the project. This is an open-ended problem in which much needs to be defined and analysis is a tool, not an end.

Students will be assigned a project and develop methods to accomplish the goals and assess the success of their approach. Students will formulate questions, develop strategies to find answers, and then find ways to test those answers.

Assignments for the course will lead to the construction and testing of a physical model, such as providing students with hands-on experience in the use of sensors. Students will be encouraged to investigate non-traditional approaches to solving problems. The final report will include results of their investigation as well as a proposal and preliminary budget to further develop their ideas. Industry representatives, expert in the different areas required by the project, will assist the teams and provide feedback.

Sample projects for this course may be the design of a bridge over a wide river placing a maximum of one support in the river. The design also includes consideration of bridge embankment and the foundation/support system for the bridge as well as traffic capacity. The students will utilize computer packages to simulate response and evaluate alternatives. Students will choose one system to implement and build a model. The system will be evaluated under (1) static self-weight and weight of stopped traffic, (2) moving “traffic” load, and (3) river flow around support utilizing appropriate sensors

Senior Course: Capstone Design

This course provides general and specialty civil engineering students with a perspective of how a project can be developed using an integrated approach. The emphasis of the course is design as a means to control the built environment, i.e., controlling flood water levels, water contamination, traffic flows, building displacements, etc. under variable demand intensities due to rain, accidents, wind, and terrorist activities such as blasts, bioterrorism.

The course is driven by a term project, presented at the first class meeting, with all lectures throughout the semester supporting the development of the project work. In addition, the laboratory sections of the course will be used for project assignments and to allow students to work directly with the faculty and industry. Industry involvement at the capstone level, as currently happens in the structural engineering capstone course, is critical to the development of real projects by the students, as well as aiding students in the transition from students to industry professionals. Reports and presentations will be required and be very structured in terms of specific content and format. Students will receive feedback from both faculty and industry members on their work.

A pilot section of an integrated capstone course was given focusing on the integration of design and construction of a warehouse type building and site development located on a proposed site in the Bryan-College Station area. Within the teams of four to six students each, individuals had a primary role such as project manager, structural design, geotechnical, or construction engineer. The proposed project was developed based on the design-build delivery system. Each project team developed a design and a guaranteed maximum price (GMP) estimate plus a site plan and schedule. The pilot section was deemed a success by the students and faculty.

CONCLUSIONS

The development of the revised curriculum is an ongoing process. The framework and goals developed focus on the teaching and development of a vertically aligned curriculum that infuses new learning techniques and research into the curriculum. The project-driven courses deal with the training of students to better understand their individual learning styles and further develop them for life-long and deeper learning. Currently, the development of how to horizontally integrate existing specialty area courses onto the central core is being developed. Additionally, the curriculum revision plans include provisions to promotes further learning by training civil engineering faculty to infuse effective teaching strategies based on pedagogical research to build a strong community of learners both among faculty and their students.

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