IT as Information Technology in CE and Instructional Technology in Education

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Abstract

The fast-moving world of information technology is greatly changing the practice of civil engineering. Thus, it is generating changing needs and opportunities in education. These needed changes are both in program content and in delivery. The authors have conducted a NSF Department-Level Reform Planning Grant on the topic of "Information Technology in the Integrated Civil Engineering Curriculum", and this paper reflects findings from this effort. The primary emphasis of this paper is on the utilization of Information Technology within the civil engineering profession and in the large-scale products and systems the civil engineering profession provides, operates and maintains. Instructional technology, both general and IT is noted more as a part of implementing changes within the educational environment.

Information technology as utilized in CE can be placed into four general categories. (1) personal IT/computing tools – which all graduates and civil engineers need at a fairly high level of proficiency, (2) civil engineering systems tools such networks, data structures, highly interactive design, supervisory control and data acquisition systems, decision support systems and other IT tools applied to intelligent transportation systems, NDE, environmental monitoring and control, smart buildings, etc., (3) IT-system components – sensors, actuators, communication links, etc., used in remote systems, and (4) IT tools used in instruction, presentation, sales, and general communications. The future graduate cannot be an expert in all of these areas. The paper explores which IT topics need to be addressed at what level of proficiency (recognition, understanding, or ability) and how this might be achieved in revised courses or academic programs.

Introduction and Background

Developments in information technology (IT) and their utilization are rapidly changing both civil engineering practice and the management and operation of civil engineering systems. A critical current challenge for civil engineering education is how it needs to change, both in pedagogy and, more crucially, in its content, to better prepare its graduates for tomorrow's professional environment. What needs to be added, with what priority and what depth of coverage? How can it best be integrated into the curriculum? To make room, which existing topics may need to be de-emphasized or even dropped (very often an unpopular, difficult subject)? What knowledge and skills in which IT topics should be a basic requirement of the undergraduate program, which should be only illustrated, noted, or sampled, with proficiency to be acquired as needed by the graduate while in the profession? What is the best way to prepare graduates for future IT tools and their increasingly powerful applications?

Civil engineers have lead roles in the management and operation of infrastructure and environmental systems, as well as in the establishment of need, design, and construction of these systems so critical to our modern society. The power of IT is increasingly being utilized in facility design, construction, and operations. IT provide the tools that, when properly used, give today's and future civil engineers the power to more dependably and efficiently provide the basic amenities of modern life within increasing environmental, social, and resource constraints. An incomplete list of IT applications beyond initial design includes optimal routing and utilization of resources (water, power, fire and other emergency response actions); inventory, location, and management of geographically-distributed resources, construction productivity; monitoring of environmental quality, infrastructure integrity and system security, along with follow-up decisions; building operations (smart building), and actions to relieve traffic congestion (from basic signal control to more developed intelligent transportation features). The marketplace is driving both the opportunity and the need for the creators, operators, and managers of infrastructure systems to know well and utilize IT tools.

From another perspective, it can be observed that today's civil engineers are becoming more decision makers than the sole providers of detailed design solutions. In today's design environment, he or she has become more the user and manager of IT/computer-based design and management tools, tools which must be understood and properly used. The engineer needs both IT skills to operate these tools efficiently and the engineering skills necessary to use these tools correctly, a dual challenge for today's programs in civil engineering education.

As noted in many past and several recent calls for engineering educational reform, today's typical curricula too often reflect the past rather than looking toward the future. Information technology is a key area where educational programs have tended to lag, rather than lead, modern engineering practices. In his remarks to the 2002 ASEE Annual Conference on the urgency of engineering education reform, William Wulf, President of the National Academy of Engineering, notes[1] that with a few exceptions, "it is only a slight exaggeration to say that our students are being prepared for practicing engineering in a world that existed when we (faculty) were trained, but not for the 21st century." He further adds "…..engineering is changing! Information technology will be embedded in virtually every product/process in the future… Discrete math, not continuous math, is the underpinning of IT. It's a new fundamental." He also raises the need for a first professional degree in engineering, beyond the BS level, noting additional needs of the engineering graduate, including IT, more social and management sciences; and retention of a liberal education component, all coupled with limitations of the undergraduate programs, including the mandating of a maximum of 120 credit hours for undergraduate programs in several states.
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This call for a first professional degree had been made earlier and for many of the same general reasons for civil engineering. After extensive professional discussions within committees and conferences on civil engineering education, the ASCE Board of Direction adopted in October

1998 its Policy Statement 465, which, as revised and adopted in October 2001[2], states "The ASCE supports the concept of the masters degree or equivalent as a prerequisite for licensure and practice at the professional degree". The desired "Body of Knowledge" (BOK) to be achieved by the completion of the combined Bachelor's Degree plus 30 credits (B + 30) program includes professional practice and management topics[3]. The ASCE BOK Committee added the following four outcomes to the eleven "a through k" ABET outcomes[4] as their way to address "what should be taught and learned" in the combined BS + MS program: (12) an ability to apply knowledge in a specialized area related to civil engineering, (13) an understanding of the elements of project management, construction, and asset management, (14) an understanding of business and public policy and administration fundamentals, and (15) an understanding of the role of the leader and leadership principles and attitudes. Although these do not specifically address IT, it is very evident from their report that IT is considered a major driver of change that the civil engineering educational programs must recognize and address.

Content on relevant IT topics needs to be developed across the civil engineering curriculum. This is a difficult challenge, especially with today's usual curricular organization based on largely-independent courses each dedicated to a well-defined subjects. The integration of the new IT-based technologies into practice is changing the conduct of engineering work across all the traditional civil engineering disciplines. It has become a new engineering fundamental that must be developed and applied in many topics, not neatly confined to a couple of traditional classes on the topic. This requires new thinking about the civil engineering curriculum. It strongly suggests more integration in the organization of the engineering curriculum.

This paper reports on two related efforts at Colorado State University that are helping us identify and formulate plans to implement appropriate information technology content across our undergraduate program. The first is our existing integrated undergraduate civil engineering core sequence of eight courses (24 semester hours) that we initiated seven years ago. The second is the NSF Department-Level Reform Planning Grant on the topic of "Information Technology in the Integrated Civil Engineering Curriculum" carried out by the authors. Emphasis is given to the second, as the general features of the integrated core sequence has been previously reported[5] and is important relative to the IT topic primarily as a means by which the implementation of changes can be facilitated. As a next step, let's examine what will be included within the general topic of IT within the context of civil engineering practice and education.

The Roles of IT within Civil Engineering Practice and Systems

Information technology relative to CE practice will be defined to include any computer-based tool used for information access, sharing, and presentation; computational tasks and system analyses, data organization and presentation (including visual); and for detection, measurement, and monitoring. It can be described as the Information Technology (IT) and Information Computing Environment (ICE) within which today's engineers increasingly find they operate in carrying out designs, preparing project documents, and managing construction, routine and emergency operations, assessment, and revisions of projects of all sizes.

This information technology is changing practices in the design, construction, and operations in a wide range of applications in areas such as managing traffic flows, infrastructure monitoring, systems security, and facilities planning. In the task of defining the roles of IT within a changing civil engineering environment, it is helpful to beak the very broad range of information technology utilized in CE into four general categories. (a) personal IT/computing tools – which all graduates and civil engineers need at a fairly high level of proficiency, (b) civil engineering systems tools such networks, data structures, highly interactive design, supervisory control and data acquisition systems, decision support systems and other IT tools applied to intelligent transportation systems, NDE, environmental monitoring and control, smart buildings, etc., (c) IT-system components – sensors, actuators, communication links, etc., used in remote systems, and (d) IT tools used in instruction, presentation, sales, and general communications. These are further described below.

a) Basic personal professional-level IT skills – for near-term graduates, this may include proficiency with basic internet tools, word processing, spreadsheets, graphics and computational software, some form of programming, presentation tools, and some abilities with application software and geographical information systems (GIS). Although this set is not well defined, these skills are increasing being expected of all engineering graduates.

(b) IT tools for CE Design and Management -- CE practice extends the use of the basic professional-level IT skills to the utilization of larger and increasingly more interconnected components for CADD (computer aided design and drafting), GIS, data bases, decision formulation and support, general accounting and management, information acquisition and data-sharing systems, along with software components for scheduling, estimating, specialized design, system modeling, facilities operation and a multitude of other possible tasks. These IT tools range from those ubiquitous to most practice to those unique to an individual firm or type of organization. Their utilization varies from development by cutting edge firms to reluctant use as absolutely required. A near future demise of all paper-based design documents has been foreseen by some predictors for at least some markets and project types.

(c) IT/ICE Applications within the Engineering Artifact or System – Use of "smart" components and tools within many engineered systems, including those involving facilities and infrastructure, along with the information processing systems necessary to provide monitoring, warning, and/or control of these systems, is rapidly growing. These information systems within the civil engineering area includes smart highways, intelligent traffic control, GPS-based location and status information systems in transportation units, weight in motion and many other intelligent transportation system (ITS) components; smart buildings; robotics for construction, rescue, and hazardous operations; non-destructive evaluation; remote sensors for security, system monitoring, and structural health; along with a myriad of other applications for sensors and actuators. These applications consist of components, including a variety of transducers, linked with information processing and the management/decision makers back at the "home office" must be linked. SCADA (Supervisory Control and Data Acquisition) systems combine remote monitoring, control, and evaluation of system performance. Just as in the consumer product marketplace with its microwave ovens, toasters, and other products equipped with microprocessor units, "intelligence" is increasingly a component being provided in civil engineering systems.

(d) IT uses in Education (including "IT to teach IT") – The use of IT in the classroom, including for distance education, has properly received much attention in the engineering education literature and in educational practice. IT tools are gaining general use to present, make available, and deliver/interchange material either on site or at a distance. While very important and of relevance to our CE core sequence, IT use in the university's classrooms and other educational programs is not a primary emphasis of our examination of IT in civil engineering. Applications for consideration in our future implementation studies may include the utilization of IT/software tools for simulations and parameter studies (including virtual laboratory experiments), design options and comparisons, illustration/demonstrations of behaviors, applications and tools that cannot be covered in detail, and other ways in which the use of IT can be employed "in context" and thereby increase student knowledge of both the IT tool and the engineering topics. Note that many IT uses in education are basically the same as IT uses for communications and information exchange in engineering practice. The civil engineer presenting a project to a group of clients, a citizen group, or at other gathering has similar IT needs to the faculty member utilizing IT in education, and thus this group of IT uses overlaps those in the first group described.

The Inclusion of IT Topics in the Civil Engineering Undergraduate Program

The future civil engineering graduate cannot be an expert in all of the IT tools and applications just noted. The level of proficiency appropriate at the time of graduation – recognition, understanding, and ability – will not be the same for all IT topics. Some IT must be learned on a when-needed basis within the employment environment, instruction in other subjects need to be primarily a task for the academic programs.

Another way of categorizing the graduate's expected capabilities needs for the various IT tools is to describe how this person will interact with the IT tool. Will/should the engineering professional at the time of interest (a) be a practitioner – competent to design an artifact or complete another appropriate well defined task with the IT tool, (b) be a consumer – competent by background to generally understand the task and IT tool requirement, knowing or easily determining what specific tools are available, capable of choosing, specifying, and learning the tool as might be required, or (c) be literate about the topic -- have a general knowledge of available technology, but not competent to specify without considerable additional study. The placement of various IT tools within the scale of competency, proficient through general awareness, will differ with the engineer's education and professional development, job assignment, along with time as IT tools continue to evolve and be developed.

An early step in the incorporation of IT topics in the civil engineering educational programs is to define the basic IT components and tools, along with the levels of competency which are needed by the graduates to best function in the professional environment they will be entering, consistent with the limitations and resources of the educational systems. Future changes in the CE curriculum related to IT at Colorado State will almost certainly will come about through incorporation of IT-topics in specific courses – sometimes at the level of demonstrations to give students familiarity with the IT applications in that technical area, by new or reorganized required and elective courses devoted to IT topics, and planned changes across at least several of the courses in the eight-semester sequence of integrated core curriculum courses included in our undergraduate program. A description of this core sequence is next given.

The CSU Integrated Civil Engineering Core Sequence

The integrated civil engineering core sequence of eight 3-hour courses, one each semester, was created largely by the reorganization of existing classes and topics to give an improved environment for many important but often ill-defined general topics, especially those needing to be distributed "across the curriculum". These "across the curriculum" topics include computing skills, design concepts, project organization and management topics, technical communications, applications of statistics and risk concepts, civil engineering history, and professional issues, including ethics.

The current content of courses in the integrated CE Core sequence, along with their present quite generic names, follows. The content of each class is constantly under review and changes are fairly common as we better identify opportunities and understand restraints

CE108– Civil Engineering Principles I: The civil engineering profession, formulation of engineering problems, general computing, network use, equation solvers, professional presentations, basic surveying, group dynamics and project planning.

CE 109 – Civil Engineering Principles II: Civil engineering problem solving and design approaches, introduction to GPS, graphics and more computing skills (Autocad, spreadsheets, applications), introduction to programming (Visual Basic), reports and presentations, groups design.

CE 208 – Civil Engineering Analysis I: Theory and use of measurements, introduction to GIS, surveying data use and management, including mapping and zoning; infrastructure systems and project basics, including layout, costs and cost estimates, codes and standards, risk analysis and topics in statistics; quality in the constructed projects, life-cycle cost concepts, AutoCad and graphical presentations.

CE 209 – Civil Engineering Analysis II: Behavior and properties of construction materials, material standards, instrumentation and use of testing equipment; selection of materials, concrete mix design, use of statistical concepts to help set design values and for quality control practices, failure modes of materials and structures as a result of various types of design errors, technical reports.

CE 308 – Civil Engineering Synthesis I: Modeling, simulating and optimizing techniques for CE systems; statistical tools and concepts for CE risk analysis, time series analysis and numerical modeling; systems behavior (traffic flow, water supply systems, other), performance metrics and sensitivity analysis, project management, communications and presentation skills, ethics.

CE 309 – Civil Engineering Synthesis II: CE infrastructures systems, numerical and decision analysis techniques, statistical and risk analyses, project management, synthesis tools, multi-criterion decision analysis.

CE 408 – Civil Engineering Design I: Design of civil engineering systems; social, environmental, economic and other non-technical design considerations, engineering economics, project organization and management, design project development and operation of design teams, including formal presentations; management of firms, construction industry trends.

CE 409 – Civil Engineering Design II: Group design projects of civil engineering systems, engineering business and management concepts; professional issues, including ethics, registration, and continual learning; formal written project reports and project presentations.

The CE core sequence is a logical home for the introduction of pedagogy techniques and content changes, including those related to IT. This is the basis for our NSF Planning Grant being closely tied to our integrated civil engineering curriculum and it core sequence. The core courses can accommodate the basic IT skills and IT topics that are not limited to a single or a few traditional classes. Their inclusion is also facilitated by the coordination and dialogue among the especially the CE faculty serving as instructors of the core classes that are most involved in the overall undergraduate program. Other courses in civil engineering can build on the basic IT knowledge the students obtain from these core classes and from new or revised courses dedicated to the basics or applications of IT within civil engineering.

Planning is starting with members of the Electrical Engineering faculty on possibly revising a present "Introduction to Electrical Engineering" course now offered for non-EE majors or creating an additional course to include IT components – communication links, sensors, data storage, input/output devices, operation of integrated computing systems – some at the level of ability (the capability to perform or use with competence), others at the level of more abstract understanding or recognition. The formation of a senior-level course, probably an elective, on IT applied to CE Systems (intelligent transportation systems, environmental monitoring, infrastructure assessment and non-destructive evaluation, smart buildings, disaster management and early warning systems, etc.). These future directions will be build upon the findings of the NSF Planning Grant Project next described.

Findings of the NSF Planning Grant Project

The NSF Planning Grant project included literature review, surveys of educators and practitioners, and direct interaction with these providers and users of IT through a series of focus group meetings with Colorado area practitioners and a national workshop held April 2003 in Fort Collins. More details of the project and workshop organization and findings are given elsewhere[6].

The literature review and surveys of educators showed that journal reports of IT-based instruction are scattered and lack a central theme. IT is being implemented industry-by-industry and from the bottom up, with little coordination. While practitioners can adapt and respond to market pressures, it is difficult for academics to plan a coherent curriculum without a road map. Professors control change, course by course, and most are overwhelmed by the software now available and utilized for specific tasks in practice.

From the focus groups, we noticed the high degree of connectivity among IT components reported in anecdotal reports from groups in industry, government, and academia. Three types of connectivity noted in integrated systems (roads, pipelines, electric grids), in work (branch offices working together, shipping work offshore), and in IT systems (integrated cyber activity, from computing to communications, to presentations, etc.).

Beyond this noted trend in connectivity, the focus groups resulted in other trends and a wide diversity in the details of IT use and practices among individual organizations. Some notable themes include (1) a call to not allow the basic student abilities to understand and apply engineering concepts to be traded off for more student skills in IT. The practitioners want and expect students to be intelligent users of software and have good abilities to critique the suitability of software tools and the reasonableness of answers; (2) graduates and faculty should know that there is an increasing linkage of software tools; (3) GIS systems are becoming a common tool in practice, as are data bases, and (4) most practitioners are willing to and expect to invest some training time for recent graduates in the large IT systems they need to use, but value students having enough background that they can quickly learn.

Differing input was obtained on the level at which the new graduate needs to know AutoCad (or a similar CAD tool). Some employers expect a high level of proficiency so designer can use such software a basic design and visualization tool, with contract documents flowing from this more "sketch pad" use, while a few others noted that a lower level of such graphic skills may suffice because of the current or expected utilization of off-shore firms to produce final contract drawings and documents. A wide range of responses occurred regarding the need for specific student computer programming skills.

The national workshop reinforced many of these findings of scattered applications of IT, lack of common expectations for student abilities with various software tools, and a need for communication and coordination among the users and faculty planning the IT-component of civil engineering education. Workshop participants also provided insight into obstacles educators face in providing greater IT content in the civil engineering curriculum. Practicing engineers at the workshops felt that they experienced basically the same obstacles as do the educators. The obstacles mentioned include:

- There may be low levels of awareness of IT tools and few effective ways for teachers or practitioners to learn them. Professionals face time pressures, and their reward systems may not align with learning a broad range of IT tools.
- Software packages may have steep learning curves, and time spent teaching or learning the software may not be productively used.
- The cost of IT systems and preparation of associated infrastructure or classrooms are hurdles.
- The traditional system of autonomous classes and subjects creates barriers to planning and coordinating IT instruction and learning.
- Often there is a lack of an effective organizational champion and leader for IT.

To address these obstacles, the Workshop recommendations include that Civil Engineering Departments should increase faculty awareness and knowledge about IT and give organized planning a high priority. They should emphasize workable priorities and reward systems. They should examine the curriculum in detail and develop team approaches to classroom activities.

Competency can be increased by in-house workshops and sending teachers to short courses. For example, many GIS teachers and users learned their skills at tutorials and seminars provided by vendors.

On the question: "How are the systems changing, and are civil engineers prepared to handle the changes in technology," the key Workshop finding was that civil engineers must be prepared to work on higher-level systems, as well as to plan and design components of facilities. To prepare them better for their roles as "integrators," civil engineers need preparation in systems thinking and systems tools. These would include systems engineering, communication, human factors, modeling, network analysis, and problem-solving strategies.

On the question, "what do civil engineers need to know about IT–based components," the Workshop and research team members concluded that a new range of technologies should be studied. In addition to required science courses, which ought to cover component technologies as well as basic sciences, civil engineers should study the integrated control system, including control actuators, communication, data, and decision components. The team believes that these topics should be included in a new foundations course, which might replace the circuits course offered by some universities, and be reinforced in applied courses.

Also noted at the Workshop was synergistic ways in which IT can be used to transform the educational process. For example, departments could work with firms to gain access to a database, which could be used to study various IT applications. They can partner with industry to create practical examples of models and databases for academic uses, to develop exercises to reflect the real problems and opportunities of IT use in the profession, and to develop strategies for integration of IT in applied courses.

The Workshop and project team defined a framework for addressing IT that starts with a suite of basic IT tools that do not differ much from those needed in other fields: office applications, web, presentation, and basic computation tools. Next, it moves to computer–aided design and graphics tools. Finally, it introduces computer–aided analysis tools for the technical areas of civil engineering—transportation, structures, hydraulics, hydrology, water quality, and others. Obviously, designing the instructional approach and organizing the needed infrastructure represent challenges that remain to be solved.

These are substantive remaining challenges that include many issues about what to teach and the level of understanding to strive for. The challenge is especially formidable in the large, public university with its fragmented instructional environment. In the end, improving the instructional environment means more than deciding what to teach and how to teach it. It also requires preparing the faculty and instructional infrastructure and adapting to the need for improvement.

In conclusion, IT offers strategic problems and opportunities to civil engineers and educators. The problem is that unless the profession takes advantage of the technologies, others will, and civil engineers will be left behind. The opportunity is to use IT to reshape both civil engineering and its educational system. The challenge now is to work out the details, to include better systems instruction, clearer understanding of component technologies and how to apply them to systems, and an effective way to overcome obstacles to teach the many constantly–evolving tools that are available.

Concluding Remarks

There is little disagreement that information technology is affecting the practice of civil engineering, but the speed and extent of change are surprising. In addition to the work processes of civil engineers, the allocation of work, educational requirements and career paths, and business opportunities for civil engineering firms are also changing. These changes are leading to new paradigms for intelligent transportation, smart buildings, SCADA, monitoring and control, disaster management, and intelligent construction.

Most observations and conclusions of the IT study will have applicability for civil engineering programs in general, even though some specific plans for implementation within our curriculum will center on the core courses. IT certainly has many applications outside of the core courses, including in simulations, virtual labs, formulation and analysis of design options, demonstrations and illustrations of software and other IT tools used in practice related to the course topics, and application of personal IT skills to help meet class requirements. One task of our CE core sequence is to support the rest of the technical curriculum by students with knowledge and skills in several general areas, including IT, so they are available for use elsewhere.

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