On the Job versus Graduate School Training of Forensic Engineers—An Instructor and Professional Engineer’s View

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Abstract: This paper provides insights from a graduate forensic engineering course for civil engineers and analyses its success from the instructor and student perspectives. The objective of the study was to evaluate teaching methods and settings for training of forensic engineers in light of new body of knowledge needs for the profession. The assessment methodology used student feedback before, during, and after the semester-long course and the instructor’s observations and prior forensic engineering consulting experience. The course was structured around student learning objectives that paralleled actual engineer training in professional consulting firms. The students used hands-on learning, field investigations, library-based research, and report writing. Focus was placed on learning basic research skills and applying scientific method which were at low levels among students. This is of concern to the profession as these skills, along with analytical ability, form part of the basic tool set of most engineers. By the end of the course, writing and review skills had improved significantly and student perceptions of the specialized skills turned more favorable. The students overwhelmingly appreciated inclusion of guest lectures by forensic engineers to demonstrate the relevance of this field. It was concluded that inadequate technical writing and reading skills, symptomatic of students in many engineering programs can be corrected through a forensic engineering course.

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Introduction

There has been an upsurge in interest for forensic engineering since the formation of the Technical Council on Forensic Engineering (TCFE) in 1985, although the teaching of forensic engineering is not widespread. Public awareness of forensic engineers may be high due to the impact of several calamitous structural failures, i.e., the Oklahoma City bombing of the Alfred P. Murrah Federal Building, 1995; 9/11-World Trade Center Trade Center collapses, 2001; the levee failures in New Orleans and St. Bernard Parish after Hurricane Katrina, 2005; and the collapse of I-35W Mississippi River Bridge, Minneapolis, Minnesota, 2007. Despite these tragedies, the majority of civil engineering students receive little formal training in forensic investigation during their undergraduate or graduate programs. It is more typical for new forensic engineers to be experientially trained within the first few months/years by practicing engineers within their firm. As a result their education can be less structured and perhaps less comprehensive.

Arguably, all civil engineers are involved in some aspects of forensic engineering. One definition states that forensic engineering is the application of the engineering sciences to the investigation of failures and other performance problems. This definition describes the typical work of the civil engineer. Forensic engineers are needed to evaluate the causes of building failures and perhaps more importantly, they are also employed to assess the stability of existing structures and develop repair or retrofit methods to prevent collapse or injury of persons. Many now believe that future needs for forensic engineers will increase not diminish as our civil infrastructure and buildings age. Indeed the federal government appears willing to reverse the trends and increase spending on infrastructure projects. In anticipation of this increasing demand, this paper presents an alternative route via classroom training in addition to more traditional on-the-job training.

DeWitt et al. (2001) reports four reasons identified by the National Academy of Forensic Engineers why there is no formal forensic engineering degree offered at universities:

• It is not a standard engineering discipline, like mechanical or civil engineering because it encompasses multidisciplinary courses that cross traditional engineering boundaries;
• It is not widely known outside the profession;
• Universities have not seen the need to include failure analysis in traditional engineering programs; and
• The demand for forensic engineers is not high when compared with standard engineering disciplines.

Training of Engineers—ASCE Body of Knowledge

As the governing body for civil engineers, ASCE has established a criteria for admission to the practice of civil engineering at the professional level. Their criteria are comprised of a combination of the bachelor’s and master’s degree (a minimum of 30 credit hours beyond the baccalaureate) and appropriate experience. According to this policy (ASCE 2005), the civil engineer should be
able to not only recognize and understand concepts in their body of knowledge (BOK) (ASCE 2004, 2008), but they must also possess the ability to perform with competence in all areas, including such nontechnical (professional) outcomes as communication, project management, and leadership. A forensic engineering course can be an appropriate graduate level offering to fulfill several BOK objectives, as students must utilize skills drawn both from nongeengineering and technical courses. They must leverage their knowledge to resolve and communicate technical concepts. However, because many civil engineering curricula focus so heavily on the engineering courses, many civil engineering graduates lack the rudimentary abilities to prepare even simple illustrated reports. Engineering consulting firms demand high communication standards among their engineers and so graduates must routinely undergo very fundamental on-the-job training (or retraining) before they become productive. This suggests that in this area the educational training of civil engineers is at variance with the demands of the profession.

Forensic engineering arguably requires greater emphasis and application of scientific method, research techniques, and communication skills than other branches of civil engineering. However, it is critical that all engineers be able to analyze existing conditions and develop solutions for a range of problems, in a prescribed method similar to that used by forensic engineers in analyzing failures. Thus the specific skill set of the forensic engineer is also applicable to wider areas of civil engineering and a forensic engineering course would be appropriate for all civil engineering students whether or not they chose to specialize in forensic engineering after graduate school. Forensic engineering is an applied field with a multidisciplinary scope and course projects can involve a diverse team of students. The need to determine causes of failures presents students with opportunities to practically demonstrate the knowledge and skills learned from several courses.

Structure of Paper

This paper evaluates the teaching methods and learning objectives used in a graduate-level forensic engineering course. The course was structured around learning objectives developed to parallel actual engineer training approaches used in consulting firms, appropriately modified for the classroom. The assessment methodology used student feedback before, during, and after the semester-long course and the instructor’s observations and prior forensic engineering consulting experience. The philosophy and teaching approach used is described and the effectiveness of several assessment methods are discussed.

Background

The focus of most civil engineering curricula is on teaching new design and analysis skills. With reduced credit hours available less emphasis is placed on observational skills, reasoning, and scientific methods, and important skills of the engineer are being lost. Further, since technical writing for engineers is typically not taught by the engineering faculty, proper engineering approach to technical writing and scientific methods are not emphasized. These untaught skills are the core tools of the forensic engineer, and are almost as important among all civil engineers. The teaching of a forensic engineering course therefore is an asset to any civil engineering graduate curriculum.

The TCFE has promoted forensic investigation as a way to efficiently teach fundamental civil engineering concepts by studying how buildings and other structures fail. However, there is limited data available on the impact of forensic engineering teaching from the students’ learning perspective. In addition, there is no data to evaluate how effective such course work would be in preparing engineers to develop their own solutions for other situations and if they would feel underprepared without it. This limited data are due in part to relatively few numbers of forensic engineering courses being taught. Thus the majority of forensic engineering knowledge is learned by engineers through on the job training (Lewis 2003) and in practice.

There are two approaches considered for teaching forensic engineering: (1) taught as a standalone course or (2) taught via teaching modules distributed among several courses. Bosela (1993) supports the latter approach, because forensic engineering courses serve to remind students of spectacular structural failures, what can go wrong and how to prevent or minimize the risk of disaster. However, given the pressure to reduce curricula hours the teaching module approach has some benefits as the teaching of failures can be associated with teaching of theoretical engineering concepts. The limited number of failure case studies available was addressed by Delatte and Rens (2002) who created several teaching modules available online for use by faculty (http://matdl.org/failurecases/). A new book, Beyond Failure: Forensic Case Studies for Civil Engineers, has just been published by ASCE Press (Delatte 2008b), which presents 40 case studies organized in a format suited for classroom presentations. Delatte (2008a) showed that specific failure case studies can be used to address the Accreditation Board of Engineering and Technology (ABET)/BOK criteria directly.

Delatte et al. (2008) surveyed Cleveland State University students who pilot tested two undergraduate courses in which failure case studies were used. The results showed the failure case studies strongly supported the outcomes in the ABET curriculum outcomes, with scores above 3.5 out of 5 for all 11 outcomes. However, the lowest score registered among the sophomore group was 3.56, in response to “ability to communicate problem solutions effectively.” This statistic must be taken in context but from the standpoint of practicing engineers, excellent communication skills is what is demanded of new engineers because it is far more difficult to train persons to write decent reports than it is to train them to use a structural analysis software program.

In addition to the online resources there are several textbooks on forensic engineering available which can be used as course texts or reference materials. Several texts are available for teaching forensic engineering to civil engineers. (Feld and Carper 1997; Kaminezky 1991; Ratay 2000; Shepherd and Frost 1995) were used to cover the historically significant failures and case studies and (Ratay 2000) was used as a reference text to provide an understanding of the profession itself. As this particular course was focused on structural engineering and repairs of low rise building envelopes, two ASCE practice manuals and guides were also found useful (ASCE 2000a,b) and were used by students in preparing, proposals, budget, and reports.

Several fine examples exist in the literature of the traditional teaching approach for forensic engineering (Parfitt 2007; Rad and James 2007; Ratay 2005; Rens and Knott 1997; Reynolds 2003; Sutterer 2003; Taylor et al. 2007; Wang 2005). Each course structure varies, reflecting the special expertise of the instructors, but in general they include an introduction to the practice, technical and legal aspects of investigating construction failures and expert testimony. Important topics were case studies of engineering failures, definitions of forensic engineering, scientific methods and
research and the professional, legal, and ethical responsibilities of civil engineers. It is apparent that forensic engineering can be adapted to any particular area of civil engineering. Many courses also include practical investigations for students and some interaction with professional engineer guest lecturers.

**Perspectives on Training of Civil Engineers**

The roadblocks to developing more forensic engineering courses have been discussed by Parfitt (2007). He cited lack of experienced course instructors and guest lecturers and the difficulty in finding room within the curriculum given ABET requirements. Anecdotal evidence of this instructor suggests incoming students need to improve reasoning skills and technical writing. A graduate entering the workforce may need from 12 to 36 months further training to become a revenue-generating employee. It is felt that focus on training on the softer skills may benefit in reducing this time. Further, as an increasing number of students select the non-thesis route for graduate engineering training, the profession is losing this opportunity to enhance the fundamental skills of next-generation engineers.

A more integrative training of engineers is proposed by Wadia-Fascetti in an National Science Foundation (NSF) funded Integrative Graduate Education and Research Traineeship award (Wadia-Fascetti 2007). This multidisciplinary graduate training program of education and research in Intelligent Diagnostics at Northeastern University and the University of Puerto Rico at Mayaguez encourages trainees to participate in several unifying out of discipline courses (e.g., civil engineers take electrical engineering courses), research workshops, short courses, and weekly round table discussions that integrate social science and policy into technical problems. Students participate in an in-depth capstone style course (or Urban Studio) to apply policy concepts. As Wadia-Fascetti explains “Graduates will (become) diagnostic engineers whose training integrates advanced detection and diagnostics methods, understanding of subject physical systems and economic and management issues in civil and environmental engineering to fill a critical deficiency of expertise.” This enlightened approach to academic engineer training can be duplicated in the forensic engineering course.

**Forensic Engineering Course**

The goal was to develop a forensic engineering course with broad appeal and benefits for all civil engineers within Clemson University’s MS Civil engineering program. The course description for forensic engineering stated:

“Forensic engineering is the study of civil engineering failures including analyses of conditions just prior to the failure, load or event causing failure; methods of investigation and design of remedial measures; case histories of failures illustrating common errors and failures. Student projects involve design of remedial measures and alternatives.”

An informal advisory panel was formed to advise on course content and approach. The panel was comprised of the two guest lecturers, noted forensic engineers and teaching professionals. They provided valuable feedback throughout the progress of the course. The course focus was tailored to repair and renovation investigations for low-rise structures to take advantage of the instructor’s unique experience and research interests in wind engineering, building envelope design and structural engineering of buildings. The panel participants included:

- Narendra Gosain, Senior Principal, Walter P. Moore;
- Glenn Bell, Senior Principal, Simpson Gumpertz & Heger Inc.;
- Kenneth Carper, Professor, University of Washington;
- Linda Nilson, Professor and Director Office of Teaching Effectiveness and Innovation, Clemson University;
- David W. Fowler, University of Texas; and
- Allen C. Estes, Professor, California Polytechnic State University, San Luis Obispo.

A basic outline discussion within the first two lectures presented a forensic investigation case and discussed where and how the investigation started, decisions on what to do first, setting goals and managing expectations of results. This context was applied to both catastrophic failures (9/11 Building Damage from World Trade Center Falling Debris) and more typical investigation (Water Leakage Investigation in a High-Rise Condominium). The purpose of the second case was to relate forensic engineering to more limited investigations of the size and scope that junior engineers will handle.

The course objectives were developed to meet important outcomes of ASCE’s first edition BOK (ASCE 2004). As a minimum, by the end of the course students were expected to demonstrate competence in seven outcomes, listed below. Since that time a second edition of the BOK has been published (ASCE 2008), expanding the number of outcomes from 15 to 24, and presenting a more structured approach to the level of achievement expected for each of the outcomes. The corresponding outcomes numbers from the second edition ASCE BOK are provided in parentheses (i.e., BOK2-xx), below:

- Recognize the causes of building failures, understand the role of forensic engineering and professional and ethical responsibility of civil engineers: Students discussed considerations of the causes of failures and how engineers responded to those challenges (BOK Outcome 6, BOK2-24).
- Design and conduct field experiments: Students had to develop experimental approach through research on standard test protocols (i.e., ASTM) (BOK Outcome 2, BOK2-7).
- Demonstrate communication skills: Students developed a full range of communication skills with emphasis on technical reading and writing skills, through literature reviews, library and internet research and field investigation, observations and sketches (BOK Outcome 7, BOK2-16).
- Use of appropriate information technology: Students used Blackboard to develop a WIKI site using appropriate information technology to document their work and share results with their groups and the class. The Web portal included individual research papers found, students’ reviews of those papers in addition to pertinent information on their specific projects (BOK Outcome 4, BOK2-21).
- Prepare budgets and proposals: Students were asked to demonstrate their understanding of business policy and project management in preparing simple project budgets and developing proposal letters to conduct a forensic investigation (BOK Outcome 14, BOK2-13).
- Prepare and present field investigation reports (preliminary and final reports): Students identified problems, formulated them in engineering terms and solved open-ended problems (BOK Outcome 5, BOK2-5).
- Complete several self- and peer-assessments: Students identified their own progress through self-assessment and take re-
Details of the skills and their interrelationships under four skill levels:

**Table 1. Main Objective Categories of the Forensic Engineering Course**

<table>
<thead>
<tr>
<th>Category</th>
<th>Descriptions</th>
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</thead>
<tbody>
<tr>
<td>Definitions</td>
<td>Identify the characteristics, education, training, and tools of a forensic</td>
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<tr>
<td></td>
<td>engineer. Define failure in a constructed facility and categorize failures</td>
</tr>
<tr>
<td></td>
<td>due to design, construction errors and/or material failure.</td>
</tr>
<tr>
<td>Methodology</td>
<td>List general procedural steps in a typical forensic investigation from initial</td>
</tr>
<tr>
<td></td>
<td>client call to final report. Identify each step in reviews of case studies.</td>
</tr>
<tr>
<td>Literature Reviews</td>
<td>Locate and review forensic engineering papers in refereed engineering journals.</td>
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<tr>
<td></td>
<td>Identify the supporting evidence, main arguments and prepare written and</td>
</tr>
<tr>
<td></td>
<td>verbal summaries of pertinent findings and conclusions.</td>
</tr>
<tr>
<td>Case Studies</td>
<td>Compare and contrast the investigation procedures used and analyze reasons</td>
</tr>
<tr>
<td></td>
<td>for their use in forensic case studies. What are similarities and differences?</td>
</tr>
<tr>
<td>Project Management</td>
<td>Develop and use project management skills to produce project proposal letters,</td>
</tr>
<tr>
<td></td>
<td>including scope of work, schedules and budgets to perform a forensic</td>
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<tr>
<td></td>
<td>investigation.</td>
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<tr>
<td>Investigation</td>
<td>Conduct an actual forensic investigation and prepare a complete illustrated</td>
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<td></td>
<td>forensic report.</td>
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Responsibility for their development (BOK Outcome 6 BOK2-24).

**Objectives**

Table 1 shows the six categories for course objectives. Course objectives within these categories were further broken down under four skill levels: (1) basic skills; (2) intermediate objectives; (3) final objectives; and (4) student (self) assessments.

Main objective categories of the forensic engineering course details of the skills and their interrelationships (Table 1) are shown in Fig. 1 and further discussed below:

- **The basic skills level** consisted of revisions of prior undergraduate knowledge pertinent to this course. This included structural analysis of static structures, engineering definition of failures, library research skills, and report writing. The basic skills also included an introduction to the ethical and professional considerations within the engineering profession.

- **The intermediate skill level** covered understanding of definitions of forensic engineering, description of typical forensic investigations and case studies, and a study of building code requirements for structural design. Students were asked to develop and test hypotheses of the causes of failure, and by so doing establish reasonable approaches in an investigation. A broad range of case studies was included spanning from large catastrophic failures to wind damage of housing and investigations for more routine building failures.

- **The final skill levels** were developed to help students provide a comprehensive understanding of forensic engineering. At the end of the course students were expected to be able to develop an outline forensic plan, estimate a budget and write a proposal letter to a client. Further, a final project assessed their ability to conduct an investigation of a structural problem and produce a comprehensive forensic investigation report.

- **The Student (self) assessment level** were developed to parallel the way engineers learn on the job (through internship with experienced engineers) and in graduate research, by observation assessment and through supervised practice. This important step is necessary for the students to develop self-assessing skills and confidence in their abilities before addressing the final objectives.

Fig. 1 shows a graphical instructional representation of the syllabus which was used throughout the semester as a roadmap for learning and to relate separate items to each other. The flow-chart was a dynamic component that was developed throughout the semester.

**Teaching Methods and Learning Experiences**

A pedagogical approach based on the ExCEEd teaching model (Estes et al. 2005) was adopted for this course. Other useful teaching resources found in Nilson (2003) were used in structuring the course. A problem-based learning approach requiring active learning, focused attention from the student, and increased awareness of what is important. Felder and Silverman (1988) found that inductive (problem-based) teaching methods were more effective than the more traditional deductive approach used in engineering courses. However, a majority of the class preferred the deductive teaching approach. Frequent interactions between teachers and learners were developed to provide opportunities to collect feedback on the course. Many techniques used in the ExCEEd model were used to anonymously collect student perceptions (i.e., 1-min essays, middest point sentence, and matching word pairs). Teaching was structured around 20-min modules, with frequent breaks to stimulate and maintain attention and interest.

The syllabus had built in flexibility to adjust to meet the learning needs of the students. High expectations for performance were established at the outset. Students were asked during an in-class exercise, to identify the characteristics they would expect of exemplary engineers. That self-generated list of criteria was collated and used as the assessment basis for the class.

In planning the lectures material was presented in several ways to accommodate the different ways that students learn. This student-focused learning approach enabled participants to develop necessary skills exhibited by successful first year engineer employees and Ph.D. level graduate research assistants. The structure selected sought to parallel the day-to-day learning of an engineer employee by presenting open-ended problems to be solved, using research, technical writing and scientific tools as well as business and project management skills.

**Online Web Portal.** A student-centered learning approach was chosen that relied upon internet-based Web portal, Blackboard (www.blackboard.com). Course materials were posted to the site and the student groups used it as a repository for their work, and reference materials. The first 3 weeks of the semester was spent introducing students to basic definitions, background, and tools used in forensic engineering, the scientific method, and to review requirements to evaluate research papers, test methods, and building codes. The students were initially wary of the extensive writing component and need to critically think through problems and present opinions.

The multidisciplinary nature and “newness” of the subject demanded that constant feedback was provided to the students. For example, one theme which emerged from responses to a 1-min essay related to students’ unease in preparing literature reviews. Students expressed frustration at being unable to grasp the topic or approach, despite having templates to follow. Clearly, this reaction is expected when any student attempts a new skill but responses suggested they did not expect to be so challenged.
instructor feedback on these essays provided assurance that they are indeed learning and progressing well. The online Web portal was used extensively to anonymously share the class reactions and opinions. Every effort was also made to provide students with the instructor’s philosophy and explanations of course organization and grading policies.

Organization of Class. The class of sixteen students was divided into four semester-long teams so as to enhance student learning and project management opportunities. As the teams developed their case studies, interim and final reports, and slide presentations, they uploaded their work product to the Blackboard site, providing the instructor and other class members with access and enabling feedback to be provided in a timely fashion. The site was able to support public and private areas, so that some material was shared with the entire class, while others were maintained for the use of each group only. This format also encouraged creative thinking and independent exercises for the benefit of the team, as well as fostering competition among the groups.

Critical Reviews and Technical Writing. Teaching of technical writing skills to engineers is difficult because the importance of such communication is infrequently discussed with students. As a result, many templates for technical reports, investigation proposals, and budgets were uploaded to the site. Most of these were adapted from actual consulting engineering reports. A particularly useful template for writing good critical reviews (and how to avoid bad ones) was found at the Faculty of Arts Web site of Monash University. Although most students had taken some writing instruction their technical writing skills needed improvement. It was considered important also for students to develop critical reading skills and to rate the merits of a published work on its scientific basis. The effort to improve individual research skills through library searches and online bibliographic databases to find case studies, building codes and other relevant materials was an important building block for work later in the semester. There was a tendency for students to accept any formerly presented information in a book or article, and they were hesitant to give opinions on the materials’ relevance.

Library and Online Bibliographic Resources. It was discovered very early in the course that students were unfamiliar with technical use of libraries and librarians. Resources were provided for bibliographic online searches and preparing literature reviews.
In addition, the students were encouraged to meet with the engineering librarian to get help locating their articles. Emphasis was placed on these aspects early in the course (much to the dismay of many students). The students were asked to find articles within an instructor-selected bibliography, review them, and upload their reviews and a copy of the article to the Blackboard Web portal. The papers for individual student review were chosen around building envelope issues, causes, testing, and repairs of curtain walls and water leakage. The articles and the reviews would be subsequently made available and used in the semester projects. This approach was used so that students became exposed to preparing technical writing for the use by their peers and using information prepared by others. Students had to search several sources, including interlibrary loans, the university library catalog, and online.

**Group Projects**

The students were divided into semester-long groups of four students, and the majority of the work (except for literature reviews) was performed in these groups. There were four types of projects of varying scope, described briefly below. All activities involved independent research, analysis and calculations, technical writing, and oral presentations. In addition, the students submitted their assessments of each others’ project and they prepared self-assessments of their performance after reviewing comments from their peers.

- **Staircase code compliance investigation (after Professor David W. Fowler):** One of the early team assignments was a practical one to investigate the construction of an existing staircase and identify any code compliance issues in its construction, design, or safety deficiencies. Students were asked to inspect a staircase in a campus building, to identify pertinent features, and to compare it to minimum design requirements as stipulated in the International Building Code. This exercise introduced students to field inspection to document the existing condition while requiring analysis with a building code that most were exposed to during their Capstone undergraduate course. The assignment also involved a technical writing component by the team who prepared a concise report summarizing field investigation results, conclusions and suggested remedies.

- **Case study of classic failures:** Four classic failure case studies were tackled by the teams: (1) Willow Island Cooling Tower Collapse; (2) Crosby Kemper Memorial Arena Roof Collapse; (3) the 1945 B-25 Bomber Collision with Empire State Building; and (4) the Hartford Civic Center Collapse. The classic failure studies enabled the examination of failures due to design error and construction and material deficiencies, and introduced students to the process used to assign responsibilities among the various parties of the construction team. The focus was to trace causes of these catastrophic failures to identifiable errors or omissions during the design and construction. Ethical considerations facing civil engineers and professional liability issues were also discussed.

- **Residential structure investigation—Tools and techniques:** A practical field investigation was included in the course involving residential duplex buildings located on campus. A site inspection was arranged for the class, accompanied by facility maintenance technicians to identify specific complaints and structural problems. This provided an opportunity to demonstrate the use of investigation tools, introduce site safety requirements and proper documentation needs in forensic investigations. After this, the student teams were asked to develop a proposal letter and budget to conduct an investigation of water leakage through exterior walls, including preparing an illustrated final report. This was preliminary to the actual semester project investigations the four teams were to conduct later.

- **Forensic investigation proposal, written report, and presentation:** A comprehensive semester-long project drew together all individual objectives of the course. Groups had to apply a scientific method to identify damage, postulate causes, and simulate failure modes. The teams were asked to create proposal letters and budgets to conduct their investigations, propose test methods to determine causes of failures, develop repair options, estimate repair costs, and prepare fully illustrated reports. The project had a defined timeline with several interim milestones in which findings were presented to the class, graded by the instructor. These goals increased in complexity as the semester progressed, and they were able to parallel true investigations as the students made further decisions after collecting additional information. The groups were not required to track their budgets during the progress in order to focus on the actual forensic activities. The four projects were: (1) water leakage and structural cracking in basement walls; (2) determination of wind uplift capacity of a residential roof structure; (3) flooding and water damage in a metal building; and (4) adhesive failure and cracking of ceramic tile on a masonry wall.

**Assessment**

Continuous assessment and feedback was sought throughout the course through various methods. This data, along with assessments before and during the course, are used in the evaluation. Student feedback was collected anonymously using an online university-run survey tool, and the survey methods were reviewed and approved by Clemson University’s Institutional Review Board. Sixteen instructor prepared questions were included with the survey to capture specific feedback on the forensic engineering course.

At the first lecture a Background Knowledge Probe questionnaire was used to obtain initial perceptions and level of understanding. The probe included questions to identify the learning styles of students. It was found that the class preferences leaned more toward visual than verbal learners, more active than reflective, and more sequential than global preferences (Felder and Silverman 1988). Still the teaching styles were varied to sometimes use the dominant styles but at other times to use less preferred styles. This approach enables students to develop more balanced learning skills.

Another important discovery was that while most students had some idea about scientific method and the application of a hypothesis, these concepts were not sufficiently clear in their minds. The course was modified to include more time devoted to understanding these concepts. Further, the students indicated little familiarity using the library and online databases to find journal articles, which suggested that they would need help in reviewing articles as well. Within the first four weeks teaching of the definitions and basic forensic engineering procedures were intermixed with exercises to improve technical writing skills and critical thinking in order to produce good critical reviews.

The midterm examination was used to evaluate the students’ ability to integrate the procedures of the scientific method, and the analysis of a scientific journal article. The students were asked to
review a research article, identify the hypotheses that researchers set out to test, and to evaluate the contribution and limitation of the study. The paper was a typical engineering subject and the exercise provided an opportunity for testing their reading skills, understanding of important topics, and their ability to communicate in writing.

In preparation for the guest lectures, students had to review case studies and other information ahead of time and respond to questions from the lecturers. During the lecture itself, class discussion focused on evaluating reasons why the student and lecturer answers differed in addition to more details on the case studies themselves. These assignments included written summaries which were also graded.

- The first guest lecture (Mr. Bell), “How to Conduct a Structural Failure Investigation,” was provided in advance with a reading assignment on investigation techniques and partial summaries of forensic case studies. They reviewed the case studies and prepared a summary of each case. The lecturer engaged the class to elicit ideas about how each failure should be investigated, what are the failure hypotheses, and who bears responsibility for the failures. The lecturer concluded each case study with a summary of the real story, illustrating the failure mechanisms and actual conclusions.

- The second guest lecturer (Dr. Gosain) presented a case study to identify causes of structural cracking in a reinforced concrete transfer girder. He provided as-built and deigned construction documents, pertinent sections of the ACI 318 codes, and a brief description of the problem and the construction method used. The students were asked to review the drawings and identify the applicable code sections, related to shear and flexural strength issues and deflections. The assignment was to develop as many failure hypotheses they could find from both the design and construction phases of the project. They also had to summarize the guidance provided by the ACI code.

A word of caution is appropriate here: these student-centered learning activities were not viewed favorably by all students. One student wrote in the anonymous end-of-semester evaluation that his/her least favorite activity was doing research for guest lectures. S/he stated “I feel one should listen to the lecture and then find out interesting topics….” Clearly, it was the instructor’s intent to stimulate active learning which entailed students doing research and/or design calculations to meaningfully participate in class discussion. By the end of the semester, an overwhelming majority of students had very favorable opinions of the guest lectures and of the “hands-on” teaching methods employed. One student wrote that “learning by doing is an important and effective method for graduate students because it is good preparation for the real world.”

Case Study Presentation Assessment. Throughout the course, students were encouraged to provide their individual opinions based on their analyses of facts presented. This method was extended to collective team assessments of the group presentation, at interim and final milestones. Each team used a worksheet during the presentations to record the strengths and areas for improvements. In addition, the worksheet asked to rate the presenting team in several categories, including knowledge of subject, clarity of objectives, organization, composure of presenters, and appropriate use of references. The worksheets were then submitted to the presenting-team to include with their self-evaluation of their performance, which were submitted to the instructor.

Final Examination. The final examination was a take-home (open-book) assignment to review documentation related to forensic investigations of a 15-story building that suffered water damage during Hurricane Isabel. The case study involved adjudication of responsibility between the building owner and insurance company as to the cause of the water leakage. The two forensic reports, one from insurance adjuster’s and one from the building owner’s expert witness were provided through the online Web portal, along with an extensive library of interior and exterior photographs taken immediately after the hurricane and during the investigations. The first question asked the students to summarize and discuss the respective arguments presented and identify the data presented to support the arguments. The second question asked each student to prepare a project proposal letter, addressed to the building owner to conduct a forensic investigation and render a professional opinion on the source(s) of the building leaks. Their letter included a proposal budget and was to be based on guidelines and prior proposals developed during the semester.

The results of this final examination showed significant improvement and understanding by the students of the fundamental concepts of a forensic investigation. The assessment indicated also that they were now capable of synthesizing several information sources, able to identify hypotheses, able to write a concise summary letter, and to develop proposals to conduct an investigation. It was heartening to note that the intensive learning methods used in the course were able to achieve significant improvements in these abilities. Although no control method was used, based on the instructor’s professional experience it was felt that achieving such gains within four months is significantly faster rate of learning than would normally occur by on-the-job engineer training.

Discussion

The current methods for training the MS civil engineer for the workplace have de-emphasized technical writing and inductive reasoning. It can be argued that the choice by students to pursue MS nonthesis degrees may reduce the intellectual rigor and training possible only through research. These developments result in the production of MS graduate civil engineers who meet the letter of ABET requirements but may fall short in the overall spirit and abilities expected of a professional civil engineer. The limitation hinders both professional practice and results in a reduced pool of qualified candidates for the terminal Ph.D. degree.

The civil engineering profession recognizes the increasingly complex world in which engineers are called upon to operate and the second edition of ASCE’s BOK (ASCE 2008) identifies greater professional breadth and specialization required. The need for expanding engineer training beyond the traditional four-year baccalaureate is recognized to accommodate the “exploding body of science and engineering knowledge” now before us. To be successful, 21st century civil engineers will need the knowledge within both technical and professional outcomes as described in BOK2. As more of the BOK’s professional outcomes will need to be taught through formalized university instruction than previously, this will create significant change in the preparation of next generation civil engineers.

The findings of this forensic engineering course have shown that despite limited knowledge and training in scientific methods, critical reviews and technical writing, a student-centered course in forensic engineering can significantly improve the student capabilities and better prepare them for the real tasks of the junior
civil engineer. The student feedback indicated that they had to work harder than in other classes to be successful although many acknowledged the work was less difficult than their other graduate classes. A grading rubric was useful in providing the categories of success. The assignment grading stressed the need for their work product to be accurate, clear, concise and understandable. That said, student estimation of the amount of work required to produce excellent results was consistently underestimated. Many apparently never considered it may take two or three drafts and several readings of a paper to produce a concise summary. Providing opportunities for students to review and resubmit written assignments (and grading each submission) was important to emphasize both the iterative nature of technical writing and practically how working as a team occurs in the workplace. The instructor should avoid caving in to the temptation to be the “nice” teacher who gives easy “A’s” in an optional course. The student feedback showed that an overwhelming majority felt the knowledge gained in the course would have a positive impact on their future careers, and that their technical writing and reasoning abilities had also substantially improved.

From the instructor’s perspective it was clear that a 4-month long forensic engineering graduate school course will substantially reduce the learning curve for the course graduates in their first jobs, particularly as this relates to their written communication skills. The course allows students to appreciate what their employers will expect of them, which goes beyond design calculations and timeliness that is needed. For the first time, students tackled a problem for which there were several “right” answers and so had to consider many factors before select an option. Engineers possessing this knowledge will be able to undertake more complex engineering projects far earlier in their careers than others who have not been so exposed. This instructor has found several benefits to the inductive teaching method, and the integration of technical writing within engineering problems. The curriculum for the Masters degree should avoid cookie-cutter problems where possible, particularly as in future it will become the entry qualification for a professional civil engineering degree.

As expected, the pace of the course was dictated by the rate of student learning. While more time could have been spent on technical aspects of forensic engineering, a conscious decision was made to ensure the students received good direction in the reading and technical writing skills—these are the skills in demand by employers. While the inductive learning approach was initially resisted by students, the value of this approach is that it benefits the students immediately in their first jobs, where they must develop engineering solutions in this way (inductively). Several opportunities were used to include practical considerations of the engineer’s job, i.e., incorporating business proposal and budget preparation directly, and not as a stand-alone subject. Students who have been schooled mainly in deductive teaching appear to lack curiosity or interest regarding the instructor’s intent on report format and style. In the course, emphasis was placed on what the client will need to make use of their reports, as opposed to the most convenient way for the students to prepare it. Thus, the students had to factor in an assessment of the background knowledge of their client before embarking on preparation of their report. The overall success of the course illustrated that creativity among our engineering students can be harnessed and that it helps to develop good writing and analytical abilities.

Engineering students need to be pushed to achieve their best, but academic instructors may lack the more effective motivators that employer possess (i.e., a paycheck). Whereas in consulting practice, the responsibility for producing consistently high-quality professional work rests with the supervising engineer, in school it rests upon the student, who can choose to strive for a better grade or not. Engineers in the workplace do not have that option (or they will find themselves without a job). Therefore, unless the engineering instructor is willing to act like a supervising engineering and reject substandard work, students will be able to set the bar at their comfort level, which is likely far lower than what is expected in the workplace.

In contrast to many student desires for learning to be in their comfort zone, this course’s goal was to push their boundaries, as the forensic engineering discipline provides few stock answers. Every investigation is unique and requires intelligent and creative solutions. Students who are only exposed to closed-form (text book) problems will find themselves ill-prepared for real world problem-solving. Conversely those graduates who can learn techniques in graduate school to creatively solve problems will be sought after and likely to make faster progress professionally. The structure of this course exposed civil engineering students to the open-ended problems in a classroom setting that will help them transition faster to the demands of the engineering workplace. A forensic engineering course can also be a useful screening course to identify those engineers with the special skills necessary to become forensic engineers. Students who engage in scientific inquiry/research and are able to write at a high-quality level are the best prepared.

Conclusions

This paper described the pedagogical approach and syllabus for a graduate forensic engineering course for civil engineers. It reported on the successes and obstacles of this student-centered learning approach that included several innovative learning activities to better prepare civil engineers for the workplace. The assessment methodology used qualitative and quantitative measures to assess improvements in the students’ understanding of forensic engineering and their reasoning and technical writing skills. The complete results of the assessment methodologies and questions will be reported in a followup paper that is currently being prepared. The paper identified several benefits of including a forensic engineering course in the graduate civil engineering curriculum.

- The results suggest that a forensic engineering course at the MS level can significantly reduce the learning curve and time taken to develop productive civil engineer employees.
- The emphasis on first principles skills, technical writing, critical reading, and knowledge of the civil engineering business will be instrumental in providing new engineers a fast start in their first engineering jobs.
- Hands-on learning should be encouraged and include real-world investigation activities and skills as well as planning and budget decisions.
- Forensic engineering training in an academic setting can reduce on-the-job learning curve for engineers, resulting in increased early productivity. Despite early (sometimes vocal) objections by students at the end of the course they exhibited confidence and higher-level abilities in tackling open-ended forensic problems.
- The students approached published materials with enlightened skepticism, questioning the methodologies and assessing the relevance of the material to the problem at hand and they were better able to present opinions and the data to support them. While the graduates of this course will not be experienced forensic engineers, it is expected they will know how to conduct
a forensic engineering investigation according to the scientific method and recommended engineering practice. They would be able to think critically and communicate with clarity and precision both orally and in writing. A structured course such as this will reap long-term benefits to the student and the profession as a whole.

References