AC 2005-862: AUTHENTIC ENGINEERING DESIGN IN A FRESHMAN "TRANSITION TO COLLEGE" COURSE

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Authentic Engineering Design
in a Freshman “Transition to College” Course

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Summary

Through a series of three hands-on, learn-by-doing projects, students prepare to enter a civil engineering program in this first-semester course. This paper documents these three projects and describes how the course is integrated with university criteria for providing a “transition to college experience.” In addition to facilitating that experience, the projects must meet authentic engineering criteria. They do so in conjunction with realistic constraints that include societal, political, economic and ethical issues.

Background

The joint engineering programs at Western Kentucky University utilize project-oriented delivery methods as a critical part of their distinctive character. Each of the three programs (civil, electrical, and mechanical engineering) offers a first-semester University Experience course (2-credit hours). In addition to providing transition experiences to the university academic world, the courses provide a home for students attempting to determine whether engineering should be their academic major. The course is also the first time that the students encounter the learning paradigm common to the engineering programs of learner, observer, assistant, to practitioner.[1,2]

Similar to many first-semester introduction-to-engineering courses in the United States, these three courses offer a variety of hands-on, learn-by-doing activities that focus on creating a stimulating and engaging environment. And, like many such courses, goals include helping the student make an informed academic major selection, provide basic computer skills experiences, develop enthusiasm for the major, and provide at least one if not several engineering design experiences. This is done all in the hope that students make informed choices (preferably to stay in engineering!), feel like they took substantive steps towards becoming an engineer, and are better prepared to “hit the books hard” and be successful in follow-on courses.

The Civil Engineering Course

The basic first-year University Experience course provides orientation to the campus environment particularly in terms of academic resources such as library and museum archives, technology and computing, advising, learning styles models, et cetera. The civil engineering course is structured around three engineering design experiences that move students along the educational paradigm of learner, observer, assistant, to practitioner. Course delivery method follows a learn-by-doing, just-in-time approach. Approximately 7 lessons of 29 were devoted to transition-related activities with the remainder associated with disciplinary specific topics including team skills training[3].

Although none of the projects to be described here are particularly original by themselves, the significant aspect is the way in which projects are used to represent authentic engineering experiences and do so in a first semester context. Features include:

- authentic engineering performance criteria,
- authentic engineering processes,
- authentic design and analysis models and tools,
- authentic scenario that can be later used in multiple courses through-out the program, and
- authentic context for introducing societal, political, economic, and ethical issues of the typical civil infrastructure project.

The three projects used in the Fall 2004 version of the course included: West Point Bridge Design, WKU Parking Study, and File Folder Bridge Design. By authentic, it is meant that the projects utilize or mimic the actual processes or criteria used in practice. For instance, the bridge projects utilize actual strength models and analysis procedures. Additionally, student teams are not placed into design competitions; rather, their design deliverables are measured by realistic standards such as strength *and* budgetary criteria. Measures such as "capacity-to-weight ratio" are not calculated since this is not a measure used in actual bridge practice.

Project 1: West Point Bridge Designer

Using the West Point Bridge Designer Software[4], students designed a truss-style bridge that met specific budgetary and strength criteria. This software was originally developed for use in an annual nation-wide K-12 internet-based design contest. Key features include integrated design, analysis, animation, and cost calculations that provide real-time performance feedback with a single mouse button click. One lesson was provided as basic instruction to the software, a small portion of a second lesson answered questions of their works-in-progress, and a third lesson was used for the students to "present" their design.

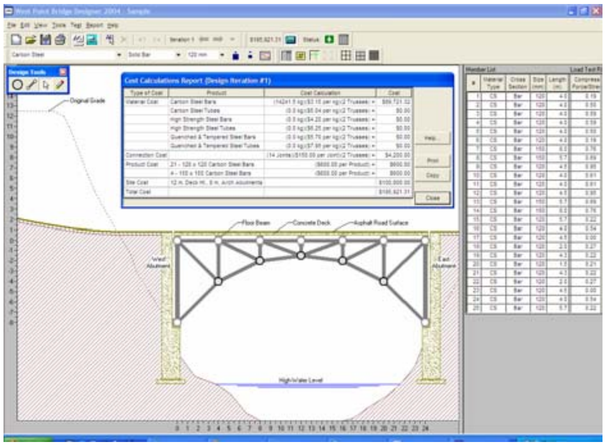

Figure 1: Drawing Board.

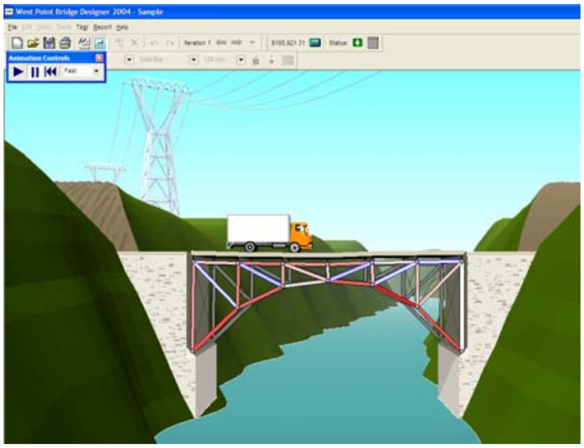

Figure 2: Load Test Animation.

By the end of the project, students were expected to be able to:

- **Describe** the difference between tensile and compressive behavior and strengths.
- Use a computer tool to **design** a model truss bridge to meet a set of design requirements.
- **Explain** how competing aspects of site, superstructure, labor, and product costs influence the selection of a design alternative.
- **Discuss** hazard and risk and implications for protecting public safety and welfare.

Authentic Engineering Features:

The most recent software versions utilize actual strength models and selected loading scenarios from the AASHTO LRFD bridge design criteria. As implemented in this course, budgetary constraints were provided instead of using a "lowest-cost-wins" style competition. That is, a successful bridge was one that not only safely supported the loading scenario (HS20-44 truck, self-weight, and impact effects) but could also be constructed within the given budget. A bridge budget of $165,000 was provided; value engineering bonuses began at $155,000.

This approach mimics more closely real design settings where, once a consulting firm has been awarded a job, merits of a design are based upon economic, social, political, and associated issues rather than what a typical "contest" implies. Students in this project were given grade incentives for "value engineering" as well as disincentives for not being able to meet the budget or provide adequate strength. However, no incentives were provided for beating (sic) other students in the class.

Project 2: WKU Parking Study

Similar to many university campuses, parking availability and capacity is perceived as a significant problem at the Western Kentucky University campus. The new campus director for parking and safety was the client for this project. The students interacted with the client to develop the scope and services. After considering various alternatives and the budgetary and human resources available, it was agreed that the students would address the demand for on-campus parking by measuring the volume of vehicles parking *off*-campus that actually had permits for on-campus spaces. This project used all or parts of 5 lessons including direct interaction with the client.

By the end of the project, students were expected to be able to:

- **Design** and **execute** a data collection scheme.
- **Evaluate** and revise a data collection scheme.
- **Analyze** and **present** numerical data using spreadsheet software.
- **Communicate** their findings in the form of a report.
- **Discuss** the social impacts of their findings.

Authentic Engineering Features:

Working directly with the client, the students developed a data collection scheme, implemented that scheme, revised it, and implemented the revised scheme. The scheme essentially involved counting parked vehicles on city streets and recording the type of university parking permits (hang-tags) for each vehicle. Empty spots were noted as well as vehicles without any university parking permits. The data were collected over two weeks as a team; students individually prepared reports using spread-sheet software to analyze the data and word processor software to prepare the reports. Unlike the other course projects where the student work resulted in a "product" that could be tested, this project introduced students to engineering work where their analysis and conclusions are the primary deliverable to their client.

Project 3: File Folder Bridge Design[5,6]

The third project of the semester involved the design, fabrication, and service-level testing of a small-scale bridge. The project followed somewhat closely the learning activities detailed in *Designing and Building File Folder Bridges: A Problem-based Introduction to Engineering*[6] with the modification of a different span, the addition of budgetary constraints, and an expanded gallery of truss configurations and analysis results. Structural material was standard manila file folder; connection strength was provided by wood glue. Span length was 25 cm; service-level strength was associated with a mid-span application of 6 kg, and the minimum factor-of-safety for design was 2.

Figure 3: Experimental Strength Determination.

Figure 4: A successful bridge.

By the end of the project, students were expected to be able to:

- **Conduct** experiments, collect and **analyze** data to **develop** empirically-based design models for structural members.
- **Design** a model truss bridge to meet a set of design requirements.
- **Construct** a model truss bridge, consistent with their set of plans and specifications.
- **Analyze** and **Assess** the performance of their model truss bridge.
- **Explain** how construction quality affects the performance of a structure.
- **Explain** the difference between system and component reliability and the implication for design.
- **Discuss** hazard and risk and implications in making decisions.

Authentic Engineering Features:

The students were presented with a scenario that included the collapse of a historically significant and locally important bridge, the College Street Bridge over the Barren River. Students worked in three-person teams to develop a design, fabricate and construct the components in that design, assemble the bridge, and place it into service. The design process followed the same used in later structural mechanics and design courses. Deliverables included member experimentation and analysis report, design calculations and drawings, and a completed bridge model ready to be tested.

Strength models for tension and compression members were empirically based and developed by the students. In essence, the students experimentally determined the salient features that influence tensile and compressive strengths of axially loaded members. Students explored various cross-sectional geometries and member lengths and used spread-sheet software to analyze and present their data and conclusions. From these, they developed appropriate strength models (formulas) that they later used in their structural design.

As a part of the design phase of the project, students are introduced to the basics of truss analysis. This introduction replies partly on their experiences from Project 1: West Point Bridge Designer as well as the critical aspects of the typical "statics" course. Emphasis was placed on a qualitative understanding of behavior rather than on ability to independently perform calculations. A gallery of truss configurations and results were provided so that even if they don't have perfect comprehension of how to derive the results their team could still successfully proceed through the design phase.

Preliminary design commenced with each student selecting a configuration from the six provided. Each student then used the strength models as a basis for selecting member sizes. Back with their team, the students developed a cost estimate for each bridge and selected what they believed would be optimal. As before with the first project, emphasis was placed on selecting an alternative that best met all criteria including budgetary as well as strength. Opportunities for value-engineering were provided in the form of bonuses for deliverables that meet budgetary thresholds.

The outcome of the design phase was a set of CAD-style drawings, a structural framing plan and a structural layout drawing. (Most students in this course are simultaneously enrolled in a CAD course, although not required as a co-requisite.) The layout drawing was printed at full-scale and used as the construction template for the bridge.

Observations and Lessons Learned

Overall, the projects were successful in generating enthusiasm for the programs and for helping the students make informed decisions about their major. Those who chose to leave the civil engineering program cited desire to try something that didn't require math and science. Those who chose to stay in the program cited their interest in the project-based approach. This isn't all that surprising given that the engineering programs at Western are highly publicized as project-based. Hence, we were preaching to the choir in some respects.

Students are disappointed that there is no clear "winner," except for the West Point Bridge Design where they see all the costs of the various design alternatives. They also are disappointed that their actual file folder bridges aren't tested to failure, apparently missing the point that civil engineers design facilities to survive, not to fail. In addition to their desire to "see carnage," they express the thought that "the largest capacity" should win. Again, they seem to miss the point their responsibility to their client is not always measured in terms of least amount of material used nor in largest capacity given an amount of material. They seem to overlook the different paradigm that operates in the typical civil engineering project --- overall usage of assets and the associated safety and functionality of their design will not always be measured in single or simple ways.

What is not clear and requires significantly greater research is the long-term effect of using "authentic" engineering projects. The pedagogic validity of using projects that represent more realistic and authentic constraints exists. However, challenges are present for application at this institution. The available sample size is small (about 20 students per incoming class) and the programs are new (first cohort graduate in the 2003-04 academic year). Hence, clear and substantive data is not yet available regarding longitudinal impacts of the approach. From prior experience implementing the bridge-associated projects at another university, it is anticipated that there will be significant impacts in both retention of students and of knowledge[5].

For future implementations, specific budgetary and geometric constraints for the bridge projects will be adjusted. In the case of the West Point Bridge Design project, some students clearly spent little or no effort in satisfying the budget. A more exhaustive examination of design options will be needed to provide a sufficiently robust challenge. The file folder bridge project will likely de-emphasize the "statics" content and emphasize a qualitative-based understanding of the structural analysis results. To that end, physical models such as those made from the children's toy K'Nex® will be useful. Additionally, a more rigorous approach to the experimental data collection and resulting data analysis will improve the understanding of where their later design models originate. Finally, the parking study should be continued but with less emphasis on the "design" of the data collection and more on teaching students how to analyze data and present conclusions.

Bibliographical Information

1. Lenoir, J., "The Wobbler Steam Engine: A Connection Between the Past, Present, and Future of Mechanical Engineering." *Proc. 2004 ASEE Annual Conference*. ASEE, Salt Lake City, UT, 2004
2. Lenoir, J., and Russell, J., "The Roles of the Student in a Project-Based Engineering Curriculum." Presented at the International Conference on Practice-Oriented Education: Transforming Higher Education, Northeastern University, Boston, MA, 24-27 April, 2001.
3. Schmucker, D, "Leadership Through the Backdoor: Exercises for Teams and Individuals," *Proc. 2004 ASEE Annual Conference*. ASEE, Salt Lake City, UT, 2004.
4. Ressler, S., *et.al.,* "Using Information Technology for Nationwide Engineering Outreach to Middle-School and High-School Students: Assessing the Outcomes," *Proc. 2004 ASEE Annual Conference*. ASEE, Salt Lake City, UT, 2004.

5. Schmucker, D., “Not As Bad As It Seems: Teaching Probability and Statistics in Civil Engineering,” Proceedings of the 2004 ASEE Annual Conference and Exposition, 2004 ASEE Annual Conference, Salt Lake City, June 20-23, 2004.
6. Ressler, S., *Design and Building File Folder Bridges: A Problem-based Introduction to Engineering*, US GPO, 008-022-00328-2.

Biographical Information

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Doug Schmucker teaches in the Dep’t. of Engineering at Western Kentucky University. He graduated from Valparaiso University with a B.S.C.E. in 1990 and earned M.S. and Ph.D. degrees from Stanford University in 1991 and 1996, respectively. He has taught courses in mechanics, structural analysis and design, materials, soil mechanics, hydrology, probability and statistics at Penn State, Valparaiso, and Western Kentucky universities.