Before Senior Design – Integration of Project-Based Learning in a Multi-Course Structural Engineering Sequence

Kevin G. Sutterer, P.E. and Thomas J. Descoteaux, P.E.
Rose-Hulman Institute of Technology

Introduction and Background

Undergraduate civil engineering design courses should feature a prepared instructor (mentor) facilitating a quality course curriculum to motivate students to use a suite of resources (including the mentor) to learn and understand the subject. Some undergraduate civil engineering design classes are required for all civil engineering students, while others are elective courses. Class makeup in these two types of design courses can be quite different, and this should influence the design of the course. Elective courses are generally populated by students genuinely interested in the subject and more likely to pursue engineering practice in that subdiscipline. Since it is rare that a single civil engineering subdiscipline is preferred by over 50% of the students in a department, it is likely the majority of the students in a required design class do not plan to specialize in that subdiscipline. However, their own specialty will often require a good understanding of how specialist civil engineers in the other subdiscipline do their job so they can effectively interact with those other professionals. In order for all civil engineering graduates to understand each subdiscipline's design process, fundamental theory, and basic tools, required design courses should be assigned the following goals:

1. Provide a foundation for subdiscipline specialization through elective courses, including knowledge of the "system" design in each subdiscipline.
2. Provide sufficient learning to allow productive and efficient communication and collaboration between civil engineers in different subdisciplines.
3. Impart sufficient knowledge of the subdiscipline to allow civil engineers, through life-long learning, to move from one subdiscipline to another as market conditions dictate.
4. Help students discover the subdiscipline where they prefer to begin their professional careers.
5. Excite students about civil engineering and inspire them to do their best in each subject.

Exciting the students is an important part of the course design, as students who are excited about the subject can be mentored to acquire more knowledge, and more importantly, are more likely to understand that knowledge. Emotion is a powerful tool for motivating students. Ideally, excited students will be motivated to learn more on their own so that class meeting time can be used for clarifying difficult concepts, mentoring, and active learning.

In the cognitive learning domain (*1*), the lowest level of learning is knowledge, with successively higher levels being comprehension, application, analysis, synthesis and evaluation. Traditional required undergraduate civil engineering design classes are generally focused on "textbook" learning at the knowledge, comprehension, and application levels. To be fair, the textbook knowledge of civil engineering design acquired in traditional courses has well served generations of civil engineers, but it is possible, through more thoughtful course

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design and facilitation, to increase students' understanding of the design process at the analysis and synthesis levels without sacrificing and perhaps even enhancing traditional textbook knowledge. In fact, careful course facilitation can also enhance student learning in the social domain (communication, teamwork and management). This paper describes three successive civil engineering design courses that have been connected to enhance student learning without sacrificing traditional textbook knowledge.

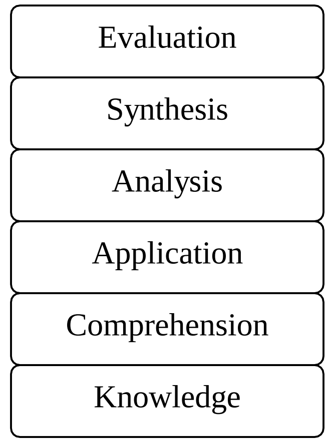

Figure 1. Levels of learning in the cognitive domain *(1)*

Rose-Hulman Institute of Technology (R-HIT) conducts courses in a 10 week quarter system. In the junior year, nearly all civil engineering students take the required courses *Soil Mechanics* in the Fall Quarter, *Structural Design in Reinforced Concrete* (Concrete Design) in the Winter Quarter, and *Structural Design in Steel* (Steel Design) in the Spring Quarter. Design and revision of these courses to their current state was not a formal process, but rather the outcome of unplanned brainstorming, reflection on student evaluation results, interaction with professional colleagues and discussions that often open with comments like "Wouldn't it be cool if..." and ending with "Let's give it a try!" However, a decision to significantly change a course curriculum cannot be taken lightly due to the risk of a failed learning process, and was not taken lightly here. So while the work described herein is still in progress and there is no formal curriculum design program under way, each change that was made in the courses was made cautiously, and performance on learning assessments (tests, quizes, etc.) was compared to prior classes to assure the faculty that learning was enhanced and not hampered.

Though not a formal process, the evolution of these courses has been the outcome of an iterative process that can be formalized as similar to the "backward" design process (*2*). Backward design consists of a staged approach to curriculum design, consisting of 1) identify desired results, 2) determine acceptable evidence, and 3) plan learning experiences and instruction. To identify desired results, curriculum designers should identify knowledge associated with the subject being learned and prioritize that knowledge in one of three types (*2*): (a) "enduring" understanding, (b) important to know and do, and (c) worth being familiar with. Acceptable evidence that the desired results have been achieved requires assessment of learning. Assessment may be one of three general types: content-focused quiz and test questions, open-ended problems that require critical thinking, and authentic performance tasks and projects. Wiggins and McTighe note the third stage in backward design, planning, requires consideration of several key questions, quoted from (*2*):

- What enabling knowledge and skills will students need to perform effectively and achieve desired results?
- What activities will equip students with the needed knowledge and skills?
- What will need to be taught and coached, and how should it best be taught, in light of performance goals?

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- What materials and resources are best suited to accomplish these goals?
- Is the overall design coherent and effective?

In the three courses described herein, students work all three quarters on design of a campus building on the Rose-Hulman Master Plan for campus development. Within the courses, the students learn through open-ended project assignments for building design, and across the courses the students build knowledge of the structural design process and learn more efficiently by saving time in project familiarization. In 2000-2001, the three courses completed a geotechnical investigation, concrete frame and floor design, and steel roof design for a planned parking garage on the R-HIT campus. In 2001-2002, student teams are working on the geotechnical investigation, concrete frame, and a steel frame alternative for a proposed Biology/Chemistry building on campus.

Desired Results

The desired results of the ongoing course development are:

- Better student understanding of the structural design process from the initial geotechnical investigation through structural frame design
- Motivate students to work harder to acquire broader knowledge of and better understanding, use, and interpretation of structural/geotechnical design tools
- Maintain or increase the traditional course levels of cognitive learning in language development, information processing, and critical thinking (textbook knowledge)
- Enhance skill development in communication, teamwork and project management

Acceptable Evidence

Acceptable evidence of progress in the course development is being assessed using four independent tools. These are:

1. Tests and quizzes of equal or greater difficulty as those administered prior to course modification. Both instructors decided prior to any course modification that student performance on traditional tests and quizzes over the same material as that covered prior to modification must remain the same.
2. R-HIT teaching evaluations are routinely administered for all courses, and course-specific student surveys are being regularly administered in some of the courses. A final survey of students completing the three course sequence was also distributed.
3. Assessment of performance on project assignments which are authentic open-ended problems requiring critical thinking and task performance comparable to that of an engineer in training after graduation.
4. Faculty perception of learning is a qualitative measure that cannot be disregarded. As a part of course assessment, the faculty reflect on successes and failures in their classes and discuss in writing their suggestions for continuous course improvement.

Learning Experiences and Instruction

The three courses are currently in different stages of development and are facilitated by two different faculty in the department. Soil Mechanics (Fall Quarter) developed slowly in stages over the past 6-8 years into a course with lots of project-initiated learning and completion of a

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valid preliminary subsurface investigation of a proposed two or three-story structure. The course was significantly modified from traditional form because the faculty determined that students must, in addition to learning theory, design tools, and lab methods, *understand* the geotechnical design process and must be able to recognize and interpret (understand) a quality geotechnical report. The final transition of this course to full open-ended project-based work benefited greatly from the encouragement from faculty using a similar format for three geotechnical courses at Monash University in Melbourne, Australia (*3, 4*). In Soil Mechanics, the quarter-long project is carefully planned so the students have to work on most of the lab, theory, and design challenges of a traditional soil mechanics course. Any lab or design/computational work that cannot be incorporated into the project work is covered by independent assignments that are not part of the project. Learning is driven by the students' "need to know" for their project rather than the order of chapters in a text or a planned syllabus. The project is completed through assembly of a "client quality" subsurface investigation report. This final report assembly is considered crucial since most civil engineers need to understand the origin, formation, and uncertainty in recommendations associated with such geotechnical reports. Since planning a geotechnical investigation requires assumptions about potential structural aspects of the facility, the course also includes an introduction to structural systems topics such as tributary area, code-based selection of expected live loads, estimation of dead loads, and effects of differential movements on structures.

The second course in the sequence, Concrete Design (Winter Quarter), developed more quickly over the past three years. Clear student feedback and increased faculty confidence in risk-taking allowed the course to evolve more quickly. Much of the class is still lecture-based with some time set aside for group work. Students participate in groups or individually in the design of a proposed two- or three-story concrete frame. Some of the load computation and building visualization time is saved since students worked on the same structure in Soil Mechanics the previous quarter. Students are not expected to design the entire structure, prepare structural drawings, or use sophisticated design software because the focus is on the design process, basic tools, and mastery of the ACI code as a crucial resource. Learning is accelerated by skipping work assignments with simply supported beams, T beams and short columns and replacing these with continuous beams, one-way slabs and slender columns. The accelerated schedule allows students time to design a significant part of a structure, including some design of moment-resisting connections, bar cutoff lengths in beams, and footings. Students are given extra credit for doing design work beyond the assigned slab sections, beams and columns. Often, students who do not need extra credit take advantage of this opportunity because of their personal interest in structural engineering and because the spreadsheet design tools they have developed allow efficient completion of some extra credit work. End of quarter project submittals consist of sketches of recommended cross-sections, side views, and connection details along with supporting calculations, with no effort to make the final product "client-quality."

Project work was incorporated into Steel Design for the first time in the Spring of 2000 as a stand-alone truss design (tension members, compressions members, bolted connections) independent of what was done in the Concrete Design course the previous quarter. The following year the decision was made to try and integrate the Steel Design project with the Concrete Design parking garage from the previous quarter. The students were charged with designing a gable roof structure (again, simple trusses as the previous year) for the parking

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garage so that it would be a better aesthetic "fit" with the other campus buildings. This year (Spring 2002), the students will continue the work they began the previous quarter designing the proposed Biology and Chemistry building. They will redesign the reinforced concrete building in structural steel (most likely a series of braced frames). Much of the load estimation work for this building will already have been done in Concrete Design thereby allowing the students to jump into beam, column, and connection design much more quickly.

Coordinating the three classes has not been difficult. The faculty mentoring Soil Mechanics develops the project each year, but discusses important aspects of the project with the other faculty during the planning. Both faculty found that use of a simple two story structure as a project is about right for the students, providing sufficient complexity without overly complicating the project effort for students in each of their three classes.

Assessment Results

Student performance on equivalent tests and quizzes has remained the same or improved since the course modifications began. This was not surprising to the faculty, since tasks completed by students include the same activities they did in homework assignments, and the faculty have made the same reading/study material in the books "fair game" for the test. The faculty have shifted classroom time from language development and information processing to critical thinking and problem solving, shifting responsibility for the lower learning levels to the students' time. Of course, the faculty remain available to answer questions on language development and information processing knowledge. Specific data is not provided here since the sample is still small with only one to three years of class results to compare to past performance.

The findings from standard R-HIT teaching evaluations are mixed so far. The open-ended learning being conducted in these classes challenges the students to actively participate in their learning throughout the quarter, rather than in short spurts before tests and when homework is due. The level of stress is higher when doing open ended learning due to lack of defined parameters and textbook style problem statements. Finally, the Soil Mechanics class is being administered with a "just in time" learning style in which students request lectures and guidance and the faculty promptly provides those. Otherwise, the students complete their work using the textbook and other resources assembled by the faculty to assist them. This learning style, while much more efficient if carefully administered, is not popular with many students. It is not unusual for students to rate faculty organization and quality of instruction lower than traditional lecture-style courses. However, positive remarks about the project-based work significantly outnumbered negative remarks in written student comments, and negative remarks generally followed the vein of saying they liked the project work but would prefer being told exactly what to do, what properties to use, and what formulas and assumptions to work with.

In addition to the standard R-HIT evaluation forms, an end of year survey was distributed to the students in the Spring of 2001. The questions asked and results are shown on Table 1. The questions were posed so that scores higher than 3.0 on all but the first question indicated support for the learning style. A score higher than 3.0 on the first question merely indicated a preference for lecture style learning. Written comments were invited from students to supplement the numeric data in Table 1. The written comments highly favored continuation of the course sequence format, with some helpful modifications. Though the students felt the workload was

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heavy, they also felt the learning experience was worthwhile. The survey also assessed the student interest in design subdiscipline, finding 43% interest in structures, 27% in hydrology/hydraulics, 19% transportation, 11% materials, 3% environmental and 5% uncertain.

Student performance on the open-ended, authentic project assignments varied from student to student. Some students who were known for exceptional work in traditional courses also did exceptional work in these courses. Others did not. Similarly, some students known for less than exceptional work performed to their normal standard, but others did much better. There was qualitative evidence that student performance in open ended project assignments could not necessarily be predicted by past performance in more traditional undergraduate engineering classes.

Table 1. Results of End of Year Student Survey (2000-2001 academic year)

Circle the value indicating your opinion, 5 = strongly agree, 1 = strongly disagree

Average	Std Dev.	
3.41	0.86	I prefer a highly structured, traditional lecture format.
3.18	0.99	I am more comfortable with open-ended design due to this experience.
3.86	0.82	I have a better understanding of how the structural system (foundations, walls, floors, and roof) all works together to produce a safe and properly performing structure.
3.86	0.83	Disregarding my personal preference for the subject matter, I think I have a better understanding of the limitations and challenges faced by geotechnical engineers.
4.00	0.82	Disregarding my personal preference for the subject matter, I think I have a better understanding of the limitations and challenges faced by reinforced concrete engineers.
3.92	0.98	Disregarding my personal preference for the subject matter, I think I have a better understanding of the limitations and challenges faced by structural steel engineers.
3.18	1.24	I believe I am more prepared to evaluate a soils report than I would have been in a traditional course without the project work.
3.65	1.11	I believe I am more prepared to evaluate a reinforced concrete design than I would have been in a traditional course without the project work.
3.53	1.08	I believe I am more prepared to evaluate a structural steel design than I would have been in a traditional course without the project work.
3.51	1.16	I recommend the year-long project format with more open-ended design be continued in some form next year (suggest modifications on the back).

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Faculty perception of the success of the three course experience was that it was a worthwhile endeavor. Student learning seemed to improve, particularly in the area of understanding of the knowledge acquired. The excitement about working on a real project was helpful in motivating students to learn more. Although students were not as happy about the workload, the positive remarks about the quality learning experience suggested that a better balance between workload and student motivation was achieved.

Lessons Learned

1. Students have a difficult time working out loads for structural design of a real structure. This was one of the more difficult visualization exercises for many students as they worked on determining cross-sections and sizing members. Interestingly, many traditional civil engineering curricula do not feature a course or module dealing with this.
2. Faculty must be patient when switching to open-ended project-based learning. Students will resist this type of learning because it makes them think harder. The time commitment in this type of learning may not be greater, but there is a higher stress level. It generally takes faculty and students 2 to 4 years to adjust to the new learning style, and discouragement on the part of faculty and students can be a problem during the adjustment.
3. Grading of open-ended project work is generally more time consuming than grading of traditional homework assignments. As the authors become more familiar with the grading/review process for open-ended work, they are discovering ways to make the process more efficient, and through practice they may eventually spend an equivalent amount of time grading student work as in a traditional course. Tools used include standard forms for reporting summaries of design work, resubmittal of previous graded work with later assignments to provide continuity, and high emphasis on organization of the submittals to assist the grader in locating specific work.
4. Some students will not like open-ended design work at all, and some will love it. It is not possible to predict how a student will respond to this type of learning based on their past performance.
5. Much of the material traditionally learned in design courses through end of chapter homework problems can be learned more quickly through planned, open-ended projects, and while doing this learning, students are also learning more about the design process and working harder on what they refer to as “real” engineering.
6. Students who did not follow the three course sequence because their schedule was out of phase with most of the class had no apparent difficulty getting up to speed in their group work and being active and contributing team members.
7. Group work is beneficial but risky. Inevitably, some students do not carry their share of the workload, so teammates step forward to do more towards completing an acceptable project. The penalty for failure to perform in “real world” teams is higher (loss of job or income) than for failure to perform on teams in the classroom. Further, students are not likely to be as tough as they should be in assessing a teammate’s weak performance. So group work can permit some students to get a higher grade on their project effort than they deserve, and cause other students to get a lower grade than they deserve. Project evaluation must be designed to minimize this as much as possible.

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8. Students need to be eased into project-based learning. To assist this process, one of the authors has initiated a less complicated project-based effort into his sophomore level course for civil engineers, Mechanics of Materials *(5)*.
9. This course coordination effort seems to have significantly enhanced student learning, yet was an unfunded outcome of an informal evolutionary process that required faculty interaction about their courses. There was no department mandate that this work be done, and no funding agency supporting the research. Faculty should be encouraged to find ways to take action on good ideas that are do-able without waiting for funding or administrative approval.

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Biographical Information

Dr. Kevin Sutterer is an Associate Professor in the Department of Civil Engineering at Rose-Hulman Institute of Technology. Prior to joining Rose-Hulman, he was a faculty at University of Kentucky. He has also worked six years as a consulting Geotechnical Engineer.

Dr. Thomas Descoteaux is an Associate Professor in the Department of Civil Engineering at Rose-Hulman Institute of Technology. Prior to joining Rose-Hulman, he has also taught at Colorado State and Merrimack College and has worked six years as a consulting Structural Engineer.

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