AC 2007-2259: SOME KEY ELEMENTS TO A SUCCESSFUL DESIGN-BASED COURSE

Blake Tullis, Utah State University

Steven Barfuss, Utah Stat University

Some Key Elements to a Successful Design-Based Course

Abstract

Design-based courses often afford instructors more latitude in teaching styles and curriculum (inductive teaching/learning), relative to the more traditional courses (deductive teaching/learning). With some effort and planning, design-based classes can be developed into a successful alternative learning environment. Three key principles, which have been found to enhance learning, are discussed. These principles include integrating lab and lecture topics, promoting student enthusiasm, and providing exposure to real-world engineering. The suggestions and techniques presented in this paper come from the authors' experiences associated with developing and teaching a design-based hydraulic structures course over the last six years at Utah State University.

Introduction

Design-based courses often afford instructors more latitude in teaching styles and curriculum, relative to the more traditional courses. With some effort and planning, design-based classes can be used to develop a successful alternative learning environment. The suggestions and techniques presented in this paper come from the authors' experiences associated with developing and teaching a design-based hydraulic structures course over the last six years at Utah State University.

Engineering design projects, in practice, can include a large variety of activities. Tullis[1] identifies key aspects of project feasibility studies, which include: a preliminary design, legal aspects, social aspects, and environmental concerns. The skill set required for engineers to master all of these areas cannot be acquired in a single engineering design course. In addition to academic experience, real-world, professional engineering experience is also required. As such, most hydraulic structure design courses focus on the system design itself through the use of example problems ([2, 3, 4, 5, 6, 7]).

In addition to the system design, Weiss and Gulliver[5] recommend that written communication and the implementation of spreadsheet programs as additional key points for hydraulic structure design courses. Effective written communication, which should include the ability to concisely summarize key points from a design report or feasibility study in an executive summery or cover letter, is critical to insuring that the proposed solution is acceptable, to both the engineer and client, and that the solution is germane to the problem.

Because it may not be practical to incorporate all of the topics of a feasibility study suggested by [1] into a design course, instructors must select an appropriate subset of design-related topics, as well as the depth and breadth with which these topics are treated. As engineering educators, the primary goal should not be to create successful designers of engineering systems, but rather to help engineering students develop the necessary skills that, when coupled with the appropriate mentoring and professional experience, will help them become successful designers.

Once the curriculum for a design-based course has been determined, there are different ways of teaching that curriculum. According to [8] most traditional engineering courses are geared toward deductive teaching/learning (the "how"), where fundamental principles are discussed, related to a relevant example problem, and then re-applied by students to similar problems via exams. Inductive teaching/learning, according to [8] represents a more effective learning pedagogy because it focuses more on the why. With inductive learning, students are typically exposed to a problem or phenomenon in a way that it captures their interest. Once students develop a curiosity and some understanding of the application, their acquisition of knowledge changed from a passive to an active exercise. Prince and Felder[8] point out that, relative to design, a good inductive pedagogy must also include deductive techniques. For example, after students' interest has been peaked and principles taught, deductive learning activities such as fabrication and performance evaluation are necessary and useful in helping student move this experience from short-term to long-term knowledge.

Suggestions for an Effective Engineering Design Course

Using the authors' hydraulic structure design course as a case study, a few suggestions are provided that may effectively improve the teaching success of most engineering design courses. Generally, providing students with relevant design procedures and experience for every possible application that they could come across in practice is impractical and also unnecessary. Particularly in a discipline where the breadth of potential design applications is quite broad, a good design course should teach students how to gain and apply knowledge to the solution of new problems. For example, in hydraulic design, applying fundamental principles such as energy, momentum, and/or continuity can be used to explicitly solve some text book-type problems, but design problems, although based upon fundamental principles, often require engineering judgment, common sense, and empirically-based design procedures.

Once the governing equations or empirical relationships, relevant to the problem, have been identified, an analysis tool, such as a spreadsheet or other computer programs, is often necessary for developing and comparing design alternatives specific to the problem at hand. As most practicing design engineers of hydraulic structures are aware, significant gaps often exist between the current knowledge base available to engineers for design and problem solving and the actual hydraulic characteristics of a specific structure. What to do when the answer can't be found in the back of the book, or anywhere else in the book for that matter, is an important point to stress in a design course. In many cases, physical and/or numerical modeling (computational fluid dynamics) tools may be required to fill those gaps. Additionally, design engineers are required to utilize personal experience, to use safety factors to account for unknowns, and to learn from the experiences of others in their design.

In the authors' hydraulic structures design class, the students are encouraged to identify and understand the governing principles and/or equations and are given opportunities to independently review published hydraulic structure design literature. One assignment requires students to conduct a literature review and write a brief, well-summarized research paper on the design and performance of an assigned hydraulic structure, as well as produce a bulleted list of key points. Five or six students are assigned the same topic. Once the papers are written and turned in, the group must assimilate the ideas from the various papers into a single group presentation which they present to the class, along with a group summary list of key points. This experience give student a model and some confidence for with independent learning, written communication along with summarizing large amounts of information into relevant key points, and working with a group

As suggested by [1], students are also given opportunities to author original spreadsheet programs for design analysis (outfall diffuser design, ogee crest spillway design, labyrinth weir design, etc). Additionally, students conduct experiments in a hydraulics laboratory that allow them to compare the predicted and measured performance of their hydraulic structure design, thus providing opportunities for discovery. By emphasizing the process of acquiring and applying knowledge to design problems, students will develop the skill set necessary for solving new and challenging design problems in the future. Essentially, the students become acquainted with the process of solving problems, so that they can later apply this knowledge to engineering system design.

Of course, an inductive discussion (the "why") about the inductive teaching/learning approach is of value, but a deductive discussion (the "how") on inductive teaching is also important. Certainly, there are many different ways to teach design effectively; the balance of this paper attempts to illustrate some specific successful teaching techniques that seem to improve the learning environment in the authors' hydraulic structures design course.

Course Example

Along with the philosophical ideas just discussed, the development of the hydraulic structure design course illustrated here was based upon three general principles: 1) integrating lab and lecture topics, 2) promoting student enthusiasm, and 3) providing exposure to real-world engineering. The remainder of this paper discusses these principles and provides examples of how they have been implemented into the hydraulic structure design course.

Lab and lecture integration

It is apparent that the learning environment within the engineering classroom is enhanced and engineering concepts (the big picture) are more adequately retained when in-class lectures are coupled with related hands-on experience, such as laboratory exercises. When the topics and assignments of the lectures and laboratories are integrated, the learning in the lab reinforces the principles taught in the classroom and vise versa. An effective inductive/deductive learning environment is created.

Typically, in-class lectures for the authors' course revolve around governing hydraulic equations, published design methods, and the development of spreadsheet-based design programs developed by the students. The lab exercises typically include the design, fabrication, and performance evaluation of lab-scale hydraulic structures that were discussed in the classroom. New topics are typically introduced in the classroom (deductive) and re-emphasized in the laboratory. An example of this approach can be illustrated with the design of outfall diffusers.

Outfall diffuser design: This topic is first introduced in the classroom and further developed with a laboratory exercise. Each student is required to develop an iterating spreadsheet program, using energy principles and published head-discharge relationships to size orifice holes in the side of a diffuser pipe. For a constant hole spacing and fixed number of holes, the performance criteria requires that the individual diffuser holes be sized such that the flow distribution from the diffuser is uniform to within an acceptable tolerance for a given maximum allowable driving head and discharge condition.

Then, using their spreadsheet program as a design tool, the students determine hole sizes and construct a lab-scale diffuser prior to the lab by drilling fourteen holes spaced 3 inches apart in a 48-inch long, ¾-inch diameter piece of PVC pipe. To emphasize the importance of constructability constraints in design, the diffusers can include no more than three different hole sizes, and of course, drill bits only come in specific sizes.

Subjected to a common upstream pressure [2 pounds per square inch (psi)], each diffuser is evaluated based on its ability to pass the prescribed design total discharge and maintain the required port discharge uniformity. A diffuser test is shown in Figure 1. The importance of quality control in the fabrication process often hits home with students as the influence of crooked holes and non-deburred diffuser ports on discharge performance become apparent.

Figure 1. Students testing a lab-scale diffuser for port discharge uniformity.

While viewing the operating pipe diffuser in the laboratory, the students are also able to see the effects of pipe velocity and pipe pressure on diffuser port discharge efficiency. They also learn that it can be difficult to build a structure or device exactly like the output of a computer program indicates. It is one thing to design a perfect widget, but another to ask someone else to build it exactly as designed for a reasonable cost.

Weir design: In some cases, a more inductive teaching approach is used as new topics are introduced in the laboratory first. Students are given the opportunity to design, build, and test a structure with limited knowledge of that specific topic. These design experiences often provide students with opportunities for discovery through both their successes and failures. The observations, successes, and failures of the laboratory experience typically enhance the students' enthusiasm relative to that topic when the topic is developed in the classroom. The weir design section of the class is an example of this approach.

Each student or lab group is required to design and build a weir using strips of plywood mounted to a plywood base. Armed with nothing more than the basic weir equation, students design and build a weir with the objective of efficiently pass two specified flow rates, one high and low, at minimal upstream heads. Figure illustrates three such weir designs from a recent class. The students are also given the choice of how the weir is oriented (i.e., upstream of downstream), relative to the contracting wing walls located in the laboratory flume. To stress the concept of balancing performance and economy and to insure that the longest weir will not necessarily be the winner, a penalty based on weir length is applied and subtracted from the weir performance score. The discoveries made during this lab prepare the students for subsequent classroom discussions regarding weirs and weir performance.

Figure 2. Examples of three different weirs designed and constructed by students

Promoting Student Enthusiasm

The hydraulic performance of physical structures is not always consistent with the theoretical predictions. As such, the appropriateness of assigning lab grades based on the ability of the student-fabricated structure to meet the specified performance objectives is questionable. In this class, the reward for developing an appropriate design, based on an analysis from a commercial software program, an original spreadsheet program, or hand calculations (the appropriate design method varies by assignment), is a good lab score. The reward for fabricating a lab-scale hydraulic structure, such as a weir or outfall diffuser, that most accurately matches the required performance criteria is a coupon for a free ice cream cone and bragging rights.

This approach not only creates an environment of academic fairness (luck has been removed from the grading process) but it also plays a significant roll in increasing the level of student enthusiasm in the class. Students have reported spending weekends in their backyard with a hose and 5-gallon bucket, trying to fine-tune a weir and orifice outlet design for an upcoming lab-scale detention pond/flood routing lab.

In addition to the increase in student enthusiasm due to exposure to real-world engineering experiences, student enthusiasm has also been found to be a function of course diversity. Varying teaching styles (inductive/deductive) also help to maintain student interest and enthusiasm.

Exposure to real-world engineering

A successful method for preparing engineering students for life after graduation is to reinforce classroom learning with exposure to real-world examples. As an example, when the topic of flow measurement with differential pressure flow meters is discussed in class, the discussion is coupled with a field trip to visit a local meter installation where the principles discussed are being applied. In addition to reviewing the flow meter discharge equations, discharge coefficients, manometry, and building and testing orifice meters in the lab, the field trip helps the students understand that what they learned in class and lab has direct application in engineering projects.

As part of the spillway design section, the class visits a large local dam, which features a duck-bill service spillway with a tunnel spillway chute, a low level outlet works with a free-discharging fixed-cone valve, and a fuse plug emergency spillway (See Figure 3.). Student feedback consistently indicates that, in addition to emphasizing the concepts taught in class, the dam field trip is continually a highlight of the course. During each field trip, the students are able to talk to the owners, operators and/or engineers in charge of the structure and by so doing gain a better understanding of day-to-day operation issues. These interactions help students realize that in addition to the appropriate design and construction skills, successful operation of hydraulic structures also requires other important skills such as planning, management, communication and budget control.

Figure 3. Dam field trip (A: service spillway intake and B: discharging fixed-cone valve).

In addition to the field trips and lab exercises, once a semester, a professional engineer from either the private or government sector gives a guest lecture based on a real-world engineering project that includes ties to the topics taught in class. Exposure to real world engineering projects helps build student interest and enthusiasm and often helps students mentally assemble the concepts learned in class and elsewhere into a more meaningful "big picture."

Assessment

Some form of assessment is necessary in order to evaluate the effectiveness of the teaching methods and to evaluate the effectiveness of student learning. The assessment of student learning is accomplished in the authors' course through traditional means (i.e., homework and lab assignments, group presentations, a written research report, quizzes and a comprehensive final exam). The authors' design course also addressed three of the ABET outcomes: 1) Ability to solve engineering problems, 2) Capacity for investigation and experimentation, and 3) Experience with written and oral communication. In addition to formal course evaluations, which have consistently ranked the authors' design course as "very good," many students have commented that this course was the best course they had taken in college. The learning environment, particularly in design-based courses, can be greatly enhanced that the effectiveness and level of enthusiasm with which students learn can be greatly increased by incorporating some inductive-based, creative teaching techniques.

Conclusions

With some creativity and planning, design-based engineering classes can be developed in which learning is enhanced through activities that promote discovery and real-world application. The regular use of hands-on lab exercises and field trips, in conjunction with traditional in-class lectures, along with an occasional guest lecturer from industry, are beneficial tools for developing effective learning environments. Good old-fashioned competition and a little bit of ice cream do not hurt either.

Bibliography

1. Tullis, J. P, *Hydraulics of Pipelines: Pumps, Valves, Cavitation, Transients*, Wiley, New York. 1989
2. Tullis, B. P. and J. P. Tullis, "Real-World Projects Reinforce Fundamentals in the Classroom," Journal of Hydraulic Engineering, Vol. 127 (12), 2001, pp.992-995.
3. Heyder, W. E., "New Engineer Training at Bureau of Reclamation," Journal of Hydraulic Engineering, Vol. 127 (12), 2001, pp.996-1001.
4. Chanson, H., "Teaching Hydraulic Design in an Australian Undergraduate Civil Engineering Curriculum," Journal of Hydraulic Engineering, Vol. 127 (12), 2001, pp. 1002-1008.
5. Weiss, P. T. and J. S. Gulliver, "What Students need in Hydraulic Design Projects?" Journal of Hydraulic Engineering, Vol. 127 (12), 2001, pp.984-991.
6. Finnie, J., "Hydraulic Design Example-Canal and Pipeline Inlet," Journal of Hydraulic Engineering, Vol. 127 (12), 2001, pp.1028-1035.
7. Hotchkiss, R. H., "Flow Over a 'Killer' Weir," Journal of Hydraulic Engineering, Vol 127 (12), 2001, pp.1022-1027.
8. Prince, M. J. and R. M. Felder, "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases." Journal of Engineering Educators Vol. 95 (2), 2006, pp.123-138.