The Engineering Proposal as a Tool for Teaching Integrated Design [1]

David J. Kerkes, Ph.D., P.E.
Consulting Geotechnical (Civil) Engineer
1311 Mustang Trail • Kingwood, Texas 77339 USA
dkerkes@geotechconsultant.com • http://www.geotechconsultant.com

ABSTRACT

Integrated design and/or capstone design courses seem to present a number of challenges to both faculty and students. The need for the instructor to be able to evaluate student design work outside his/her area of expertise tends to make some faculty members uncomfortable teaching such courses. The lack of well defined problems and the open ended nature of engineering design, coupled with their lack of practical experience, tends to frustrate many students in such courses. In addition, our colleagues in business and industry have definite ideas as to what should be included in an integrated design or capstone design course, and these ideas are not always well received by engineering faculty members. What is not always apparent, however, is the fact that business and industry can be an invaluable resource that can enhance the education experience for both the students and the instructor. This paper endeavors to identify some of the challenges and difficulties that seem to be common to integrated design courses and discusses how they can be met through the use of the engineering proposal as an instrument for teaching integrated design.

INTRODUCTION

One basic difficulty that seems to arise when teaching engineering design is that it does not lend itself well to a simple or unique definition. I would define design as the application of theoretical principles and engineering experience to the practical solution of technical problems. It is a creative process. When we begin to consider integrated design concepts and/or a capstone design course, any number of combinations are possible in terms of multi-disciplinary subjects, such as in the environmental field, or the integration of engineering theory with the legal, ethical, and socio-political aspects of large engineering projects. Even small projects need to combine theory with the economic and construction or production side of the problem to arrive at a practical solution. In addition, however, today's engineering graduates are entering a highly competitive global marketplace where new technologies are emerging in a variety of fields. They need to be educated in much more than just the technical elements of the problem, and interpersonal skills are becoming increasingly important. Advertisements for senior positions in business and industry put increasing emphasis on management and business development skills. That is a lot to try to fit into a course; however, I believe that the engineering proposal provides a mechanism in which a wide variety of these issues can be effectively dealt with while still providing a great deal of flexibility to the instructor.

INSTRUCTIONAL CHALLENGES

The development of an effective integrated design course is challenging to say the least, and with advancements in the various engineering fields, it is likely to remain so. Several difficulties generally appear to be common in teaching integrated design courses. First, with limited staff it is frequently not possible for a department to assign more than one instructor to teach an integrated design or capstone design course. However, it is unreasonable to expect one instructor to possess the technical breadth to review students'

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detailed designs, which may encompass several technical areas. This creates an uneasiness on the part of some faculty members, making them reluctant to teach such courses. Second, there is a natural tendency on the part of the students to overkill a problem, and their lack of practical experience frequently cause them to get bogged down in unnecessary details or to focus their efforts in the wrong direction. Consequently, a great deal of time and effort can be wasted by students with very little to show for it at the end of the project in terms of education and/or final product. Third, within the physical time frame of the course it is difficult to present meaningful design problems that the students can complete without requiring a level of effort disproportionate to the number of credit hours earned for the course. Furthermore, in a learning environment students need to receive feedback from the instructor, but projects involving substantial levels of effort can provide little or no opportunity for such feedback. Fourth, when dealing with design problems, particularly multi-disciplinary problems, it is difficult to keep the distribution of work equitable among the students. Some students will undertake major problems without recognizing that it may be too much to do in one course, while others will strive to do the absolute minimum. Attendant to this problem is the matter of assigning grades to a project executed as a team. There is a tendency for some students to carry the slackers so as not to jeopardize their own grade, and this is typically done without the knowledge of the instructor.

In addition to these challenges, there are some basic concepts that many employers would like their entry level engineers to understand without having to provide the education themselves. As a project manager who has worked with a significant number of entry level engineers, I consider the following concepts to be basic. First of all, entry level engineers must understand that the hours they spend on a project equate to dollars, and neither time nor money are unlimited on any given project. One might assume that this should be obvious, but my experience has been that it is not. In today's competitive marketplace students need to clearly understand the critical roles that the schedule and budget play in the successful completion of a project. Second, most engineering graduates have no idea how an engineering company obtains work and how critical this process is to the life of the company. They do not realize that a great deal of engineering goes into the development of an effective engineering proposal. Third, employers do not want to have to teach their entry level engineers how to write, and it is appalling to see how many graduate engineers are still in need of such fundamental education. Students need to be able to effectively express technical concepts in written form. They need to understand that as much engineering goes into developing the written report as in preparing the supporting technical calculations. Finally, the engineering proposal constitutes an integral part of the contractual obligation between an engineering firm and the client. Though this is an area that entry level engineers will not be immersed in too early in their careers, they should nevertheless be aware of the legal implications and ramifications of their work, particularly in today's litigious society.

THE ENGINEERING PROPOSAL AS AN INSTRUCTIONAL TOOL

The use of an engineering proposal as an instrument for teaching integrated design offers a means of effectively addressing the challenges outlined above. In addition, it provides a way of introducing the students to a number of nontechnical areas that will be relevant to their careers. For example, large proposals require a team effort, and the ability to effectively work with diverse groups of individuals, who may have strong differing opinions and different work ethics, is a valuable skill.

As for the requirements of the instructor, one does not have to be an expert in a given field to distinguish a good proposal from a poor one. As an example, consider the problem of improving or expanding an existing highway through a major city. One does not have to be a transportation engineer to recognize that a poor proposal would be to simply close the road during construction and let the traffic fend for itself. Similarly, to simply state that traffic will be rerouted during construction would be a weak proposal because it does not really address the elements of the problem. A good proposal would discuss such aspects of the problem as construction sequencing, schedule, alternative routes, etc. Thus the proposal requires that the students identify the elements of the problem, and possibly even develop conceptual designs, without requiring them

to present a complete solution in detail. Furthermore, not all proposals are necessarily reviewed by technical experts. In fact, a great many proposals must be written for nontechnical audiences. Therefore, the proposal must use written words to convey the author's expertise and understanding of the problem, and it is a poor proposal that endeavors to impress the reader with technical jargon and acronyms. My basic point is that it is a lot easier to read and evaluate a proposal (as the instructor) than it is to write one (as the student).

Another major advantage of the engineering proposal is that the students are limited in terms of the depth to which they can go into the actual solution of the problem. This keeps the problem at a manageable size; however, it is an aspect of proposal writing that students frequently dislike. They want to "solve" the problem; they do not want to simply write about it. Preparation of a proposal forces them to consider the problem as a whole, rather than focus on only the single part of the project that they may be assigned to. This skill is an important one for students to develop. In addition, there is often a tendency on the part of new graduates to want to apply all of their hard earned education to the solution of every problem presented to them. In other words, they do not appreciate the difference between conceptual design and final design, particularly in terms of schedule and budget.

Schedule and budget are aspects of the project that students should have an awareness of when they enter the workplace, and the preparation of a proposal affords an opportunity to teach this to them. At times a client may already have a schedule in mind, but it could be an unrealistic one. At other times the client will want to have a completion date identified by the engineer. In either case there are cost implications. "Time is money" may be a cliché, but it is astounding how many entry level engineers do not fully appreciate the fact that the hours they are paid for must be charged against a project for which an invoice will be written. The development of a project schedule and attendant total project cost helps to impress upon the students the cold, hard realities of time and money in the business of engineering. The proposal with the lowest cost may not guarantee success, but a proposal with a total cost substantially higher than that of the competition will most assuredly guarantee failure.

Actual problems are not as clearly defined as the homework problems at the end of the chapter, and many entry level engineers are intimidated by this. Therefore, it is important for them to recognize the importance of the engineering proposal in providing direction for the project because they will need to know where to find such direction once they leave the structure of the university. Basically, a proposal is to a project what an outline is to a report. As a staff level engineer, before starting work on a new project he/she should obtain a copy of the project proposal and read it.

Through the entire process the students must work on their technical writing skills. A great many students have an aversion to technical writing; therefore, the instructor should not expect the idea of preparing a formal written proposal to be warmly embraced by them. Many students do not consider this to be engineering and will not be convinced otherwise unless the instructor is firmly convinced of this fact. Unfortunately, they do not realize how much of their career will be spent writing, and for many of them, how essential this skill will be to their advancement in the profession. Projects do not end with a number on one side of an equal sign. Most projects end with a written document: if not an actual report, then often construction or production specifications. In today's litigious society it is often the interpretation of the written word that causes the biggest problem for engineers; consequently, the importance of effective writing cannot (and should not) be underemphasized to students.

ELEMENTS OF THE ENGINEERING PROPOSAL

Most proposals start with a Request For Proposal (RFP) from a prospective client, usually in writing but sometimes verbal. The resulting proposals come in many forms, and it is not my intent to discuss all the

various types; however, it would be helpful to examine the elements of a typical proposal. A general proposal format typically consists of the following:

- Front matter - This is standard to most any report and includes the title page, cover letter, and table of contents.

- Introduction - In this section some basic information is presented on the firm and its overall qualifications for undertaking the project. This is also where a summary may be given of the firm's understanding of the client's problem.

- General Discussion - This is the "sales presentation," and it requires a significant level of engineering if the proposal is to be taken seriously. Here is where the firm presents its strategy for executing the project. Project tasks are typically identified and described in this section. This is also where a discussion may be presented to inform the client of areas that may need to be addressed that were not included in the RFP.

- Proposed Program - This is the "what, when, where, how, and how much" portion of the proposal. This section presents a description of deliverables along with the project schedule and budget, as well as a project organization chart, functional flow diagrams for project tasks or phases, etc.

- Experience and qualifications - This is typically where specific project related experience is presented along with client contacts.

- Appendices - Resumes of key personnel, etc.

Two things are important at this point. First, the specific format that is selected is not all that significant because whatever firms the students go to work for will inevitably have their own format. What is important is that the students recognize that there is a format, and that regardless of the format, there is some basic information contained in the proposal that every member of the project team must be aware of: for example, what the elements of the project are; what the schedule for completion is; what the deliverables will be in terms of drawings, report(s), prototype(s), etc.; and what the project budget is. Second, there are some sections of the proposal that the students will simply not be able to prepare, but this should not deter one from adopting this approach. The advantages outweigh the disadvantages. Rather than have students waste time in creating fiction, elements of the proposal that students would not have available to them should simply be excluded, such as background information on the firm, client references, resumes of key personnel, etc. This is typically standard information that a firm pulls from previous proposals. The most important sections are those dealing with the specific RFP, and this is where the value lies as an instructional instrument. Students need to begin to develop their skills at defining the problem in terms of project scope, task items, schedule, manpower requirements, and budget. In this regard the proposal format provides a framework for the students.

There is ample flexibility for the instructor within the basic framework of the proposal. For example, an element of most engineering proposals is a statement of the problem, as understood by the firm seeking the work. The instructor can require more detail from the students than might go into an actual proposal in order to demonstrate an understanding on their part of the technical problem. In addition, the instructor is at liberty to define the design content of the proposal and may require a more extensive conceptual design than might be done for an actual proposal. Again, this is an instructional exercise, so the instructor sets the tone for the students based on the educational objectives of the course.

Some prospective clients do not want costs included in the technical proposal, and in some cases, it is a breach of engineering ethics to submit costs. Nevertheless, for instructional purposes, I believe that it is very important for students to consider the various cost elements of the project, and I strongly suggest that a cost

estimate be a part of the students' proposal. This is often an area of frustration for the students because they have no feel for unit costs and no sense of how long it takes to perform various tasks; however, this need not be a problem. The costs for everything from consulting services to equipment can be easily obtained from consulting firms, vendors, and equipment catalogues. This is exactly where engineers find such information on a daily basis, so the sooner the students learn this the better. As far as the time required to perform various tasks, for instructional purposes actual times are not too important. The instructor can have the students assign task durations on the basis of how long they would imagine that it would take them to perform the task based on their own experience, whether it is preparing a drawing, performing technical calculations, or typing a report. This will cause the students to recognize that some tasks may need to be subcontracted to another firm or specialty consultant. What is important is that the students begin to identify tasks and then begin to link those tasks to staff and costs in order to define a total project budget. They need to begin to think of engineering in terms of dollars, they need to begin to understand the concept of overhead, and they need to begin to make reasonable assumptions in terms of schedules. In my opinion, it is these concepts that are important, not the final numbers associated with the students' proposal.

GRADING TEAM WORK

The need to assign grades presents a major challenge for courses in which students work in teams, and I have applied a few approaches that I believe work reasonably well. Another advantage of this approach is that the proposal format tends to level the playing field, so to speak. The instructor can define the level of effort that the students should put into the design project by defining the scope of the proposal, and even limiting the number of pages to the proposal as some clients do. This helps to keep the work down to a manageable amount for both the students and the instructor. It also helps to maintain some consistency and equality in the grading process. While the actual RFP's may vary in scope, the instructor is at liberty to modify the RFP's to equalize the work and emphasize certain elements appropriate to the particular course.

The instructor should assign students to proposal teams, and there are two reasons for this: (1) in life we rarely (if ever) get to choose our coworkers, and (2) it avoids "cliques" and the uneasiness for some students of having to find a group to work in. Depending on the scope of the particular proposal, I have found groups ranging from three to six to work effectively. The first task of each team should be to select a team leader and identify this individual to the instructor. This is not an enviable job because part of the task of the team leader is to take the various parts of the proposal prepared by the team and pull them into a final product, and the instructor should make this clear to the students. The operative word here is planning, and the students will typically need assistance in this area. The process of preparing a proposal needs to be a coordinated one, with goals and objectives clearly defined for each individual on the team. Therefore, the next task of the team should be to prepare a detailed outline for the proposal, and this outline should be assigned a grade. The outline should identify all the elements of the proposal and which members of the team will prepare the various elements. This includes everything from the cover page to various figures that will be included in the proposal. Naturally, the more detailed the outline, the easier their work will be in preparing the whole proposal. This outline affords the instructor an important opportunity to provide feedback to the students and redistribute work, if necessary, to maintain an equitable workload for the team members. Assigning a grade to the outline forces the students to put some time and thought into the outline, and in fact, a great deal of learning takes place during this process. This is where the students begin to identify all the various elements of the project and how they relate to each other. Consequently, this is one of the most important parts of the course.

A single grade is given to the outline, which each member of the group receives since the outline was developed as a group, and it can constitute whatever percentage of the final grade that the instructor considers appropriate. The final proposal, however, does not receive a singular grade. Rather, the work done by each member of the team is graded individually. Thus, it is conceivable that one member of the

team could receive an A for his/her effort, while another member receives a D. Consequently, the students' final proposal is essentially "unedited" by the team leader (unlike an actual proposal), and some sections may be strong while others are weak, depending on who did the work. This avoids the temptation for the conscientious students to pick up the slack for the lazier ones in order to save their own grade. Naturally, in the product submitted for grading, each team member needs to identify those parts that he/she prepared, using his/her initials. This includes everything from the cover page and table of contents to the various tables and drawings, as well as each written section of the proposal. Written sections, tables, drawings, etc. can have more than one individual work on them, depending on the level of complexity; however, more than two individuals begins to defeat the purpose. When more than one individual prepares a part of the proposal, each individual receives the same grade for that part. It is important to note that the task of the team leader in pulling everything together into the final product is not a simple one; therefore, this should be taken into account in assigning the team leader's grade.

To increase the amount of feedback using this approach, I recommend that the students prepare two proposals for a course lasting a semester. The first proposal is more limited in scope than the second, and the objective is to acquaint the students with the proposal process and format, as well as the various elements of integrated design appropriate to the course. For the first proposal the instructor can choose a subject familiar to him/her because it is the concepts involved in the proposal that are important and not the subject matter itself. I essentially walk the students through the first proposal, giving considerable guidance through classroom examples, illustration, and group discussion. For example, identification of the various elements of the project is done in class by the students, and I provide them with a fee structure appropriate to the project under consideration, as well as task durations, etc. For the second (major) proposal, I provide the students with five or six actual RFP's to work with. In this way they can choose a subject in line with their areas of interest; however, I have them give me their first, second, and third choice. Then I assign students to proposal teams. Just as in real life, not everyone gets his/her first choice.

INDUSTRY INVOLVEMENT

At this point the reader may have two questions in mind. First, where does one obtain actual RFP's for use in a classroom? Second, students like to see (and will request) examples; how does one obtain them? The answer to both questions is the same. The instructor enlists the aid of colleagues in business and industry who deal with proposals on a daily basis. This is a relatively easy thing to do and provides the instructor with a wealth of resources otherwise unavailable. Firms can provide RFP's, as well as copies of the proposal they submitted, which will aid the instructor in guiding and grading the students. The actual proposal will help the instructor to answer questions from students regarding the development of their schedule and cost estimate. Typical proposals (other than the ones they are working on) can be placed on reserve in the library for students to examine for format, content, schedule, and costs. An added benefit is that the firms contacted may be more than willing to provide a senior individual to give a guest lecture. In this way the instructor has access to individuals to assist in the presentation of the course material, and a major advantage is that credibility and importance of the subject material is increased when presented by individuals working in the field that the students will soon be entering.

Yet another indirect benefit is that this approach increases industry involvement in the education process. Industry has definite ideas as to what they would like to have their entry level engineers know upon graduation, and advisory boards are only one way of obtaining such input. Industry, in general, wants to be involved in the education process, but cannot commit the time and energy involved in a semester long course. They can, however, commit to a few hours assisting with the type of approach that I am suggesting, and I have been pleased with the response that I received from my colleagues outside of academia. Still one other indirect benefit is the relationship that is established between faculty members and their colleagues in business, which could lead to collaborative research opportunities.

Establishing contact with companies willing to assist is not as difficult as one might think, and the local chapters of professional societies is one place to start. The instructor needs to realize, however, that the wheels should be set in motion at least six months before the course is taught because these individuals will need to find the time to provide assistance between active projects. As a final note, the instructor should not go directly to the president of the firm in anything other than a small company, unless the individual is known personally by the instructor. In large companies there is a better chance of success if the instructor approaches a department head or senior project manager. These individuals are generally easier to contact, and they have to deal with proposals on a more routine basis.

CONCLUSION

The engineering proposal provides a number of advantages as an instrument for teaching integrated design. While design problems are open ended, typically without a unique solution, the proposal provides a framework that allows the students to exercise their creativity yet maintains some consistency among the student groups, which facilitates the review and grading process. The nature of proposal preparation requires that the students examine the various aspects of the problem, but without getting bogged down in any specific part. It also impresses upon the students the critical nature of a project's schedule and budget, which often pose a greater obstacle to the successful completion of a project than the technical elements of the problem. In addition, this approach provides the opportunity for more involvement by business and industry in the education process, and in so doing makes available to the instructor additional resources for the course. Evaluation of a proposal requires far less expertise than does the review of an elaborate design, which eliminates the need for the instructor to possess expertise in every technical area that may fall within the scope of an integrated design course. The evaluation of student proposals is further facilitated through collaboration with engineers from business and industry who are routinely involved in the proposal process. Development of an engineering proposal further reinforces the importance of technical writing in the profession. Finally, the entire exercise can serve as a good introduction to the business world that the students are about to enter and hopefully facilitate that transition.