# Using a Capstone Design Course to Facilitate ABET 2000 Program Outcomes

**Melissa S. Tooley, Kevin D. Hall**
**University of Arkansas**

Abstract

ABET 2000 challenges colleges of engineering to produce graduates with professional as well as technical skills. Specifically, ABET Criterion 3 (Program Outcomes and Assessment) outlines the desired attributes for graduate engineers. Capstone design courses are one of the most effective ways for engineering departments to facilitate the outcomes described by ABET Criterion 3.

This paper discusses how the civil engineering capstone design course (Senior Design) at the University of Arkansas has been structured to facilitate ABET 2000 Outcomes. Criterion 3 Attributes “a” through “k” are listed and a discussion of how each of these attributes are enhanced in the course is provided. For example, capstone design courses offer a unique opportunity to learn about professionalism and ethics (attribute “f”) in a realistic, applied context. Because the department does not have a separate ethics course, an ethics unit is taught in Senior Design. The concepts learned are applied by the project teams to hypothetical scenarios specific to their projects. The key is to make the ethical dilemma relevant to their project work.

The University of Arkansas was one of the first two universities to undergo ABET review under Criteria 2000. Lessons learned from that review, and the author’s professional experience, were used to develop a capstone design course that not only provides a meaningful design experience, but also creates an opportunity to begin the process of becoming engineering professionals. Although the methods described in this paper were developed for civil engineering capstone courses, they may be useful to other engineering disciplines as well.

## I. Introduction

ABET 2000 challenges Colleges of Engineering to produce graduates with professional as well as technical skills. Specifically, ABET Criterion 3 (Program Outcomes and Assessment) outlines desired attributes for graduate engineers. Capstone design courses are one of the most effective ways for Departments of Civil Engineering to ensure the outcomes described by ABET Criterion 3. The suggestions given in this paper apply specifically to civil engineering capstone design courses, but may also apply to other disciplines.

While desirable outcomes (attributes of a graduate engineer) have just recently been outlined in Criterion 3, industry has always wanted to hire graduates with Criterion 3 attributes. Thanks to ABET 2000, academia must now make a conscious effort to provide what those that hire engineering graduates have always wanted – engineers that are not only technically prepared but professionally prepared.

In Senior Design, the capstone design course at the University of Arkansas, students are assigned to teams and take a real project (provided by local consultants) through preliminary and final design, culminating in the development of construction plans and specifications. It should be pointed out that while the projects used in senior design are "real world" projects, they are performed as academic exercises. In other words, they don't really meet the client and their plans and specs are not used for bidding purposes. The projects are conducted as if the job was real, however, and the consultants who provide them do work with students to ensure a meaningful design experience. Originally, the intent of Senior Design was to give seniors a chance to pull together the bits and pieces of technical knowledge that they had gained throughout their education. The course has the potential to give students much more – an opportunity to begin the process of becoming engineering professionals.

## II. ABET Criterion 3 – Program Outcomes and Assessments

Criterion 3 states that engineering programs must demonstrate that their graduates have certain attributes, which are listed below in order to provide structure to this discussion, followed by the methods used in Senior Design to enhance each outcome.

*a) An ability to apply knowledge of mathematics, science, and engineering*

An ability to apply knowledge of mathematics, science, and engineering is inherent to capstone design courses. In order to perform the design calculations necessary to produce construction plans and specifications, the student team must obviously have applied their knowledge of these subjects.

Also important in the application of engineering knowledge is project management. Students are required to manage their projects throughout the semester, with progress reports turned in at various milestones. Progress reports include such information as how many hours each team member has spent on the various project tasks, and then a calculated percent complete for each task as compared to the total time budgeted for that task. The progress reports are used to gauge how well they are doing compared to their original project budget, which they develop according to their project's Scope of Work. Project budgets include a breakdown of tasks required to complete the project, how many hours each task is estimated to take, and who on the project team is responsible for each task. Because of increasing restrictions on the engineering curriculum, Senior Design provides the best (and only) opportunity to give graduates this type of experience.

*b) An ability to design and conduct experiments, as well as to analyze and interpret data*

Students will have opportunities to design and conduct experiments and analyze and interpret data, depending on the type of project they select. For example, this semester students will design and conduct a traffic study for one project, and will analyze and interpret rainfall data for another. Soil percolation tests may be required for another project. Not only do they have to determine what their needs are, they must design and conduct the experiments necessary to obtain needed data, and then analyze and interpret it as required to meet project objectives.

*c) An ability to design a system, component, or process to meet desired needs*

Inherent in design is the ability to determine what the client's needs are. Because the projects in Senior Design are "real world" projects, students are expected to meet the needs of the client. The project scope is defined early in the semester, using the information from the consultant providing the data. Students are required to take the information and project requirements provided by the consultant and develop the project scope, including a project budget. Once needs have been adequately defined, students have to design the system necessary to solve the problem.

*d) An ability to function on multi-disciplinary teams*

One of the strengths of civil engineering is its diversity. Students, however, tend to segregate themselves according to who their friends are and their grade point averages, with few exceptions. In Senior Design, students are not allowed to form their own design teams. At the beginning of the semester, students are asked to rank their areas of interest (structures, transportation, land development, environmental, etc.) from first preference to third preference. The instructor then assigns teams based on students' project preferences and an equal distribution of academic ability. With team selection by the described method, project teams are more likely to have students with diverse strengths and abilities and therefore students will learn more about working with others. Yes, the students will initially resist this approach (sometimes vigorously), but they will learn much more about how to work in a team environment if they are working with students they may not know well.

It should be recognized that team members might have varying levels of motivation, and that safeguards must be provided to deal with this. Because of the project budget requirement, all team members know early in the semester exactly what they are responsible for. When the progress reports are turned in, a signature sheet is required with all their signatures, certifying that they have put in the number of hours shown for them on the progress report. Also, at the end of the semester, peer reviews are conducted wherein each person in the class evaluates the members of their team. Each person is "given" $8,000 with which to "pay" the 4 members of their team, and asked to distribute the money based on each member's contribution. Ideally, the money would be evenly distributed among the team. The class is informed at the beginning of the semester that it is possible for team members to make different grades on the same project, and this gives the instructor the ability to do this if large disparities in pay levels show up on peer evaluations. In addition, because responsibilities are clearly defined early in the semester, the instructor can adjust grades accordingly if one area of the project is of insufficient quality.

Because teams are not self-selected, it is important to give the students an opportunity to learn to work together before project work begins. Accordingly, shortly after teams are assigned, a class session is devoted to team-building exercises. This helps prepare the teams to work together, and enhances their ability to communicate and appreciate their fellow team members' abilities. Two exercises used successfully include the creation of affinity diagrams and a process flowchart. Both of these exercises not only foster and encourage working together as a team, they also provide tools to the teams for use in developing initial work plans for the design projects.

Affinity diagrams are used to deconstruct a given topic into various component parts and establish relationships between those parts. Typically at this point in the semester, the teams do not know enough about the project to effectively use this technique; therefore, a topic is given to the class to illustrate the use of the affinity diagram. One topic used successfully is "improvements to the undergraduate civil engineering educational process" – a topic about which most senior-level civil engineering students have definite opinions. In teams, students are asked to examine components of the educational process, establish relationships between those components, and identify tasks necessary to initiate improvements in the process. Each team member participates. After a given time period, teams are asked to make a very brief, informal presentation of their diagram.

The process flowchart builds on the results from the affinity diagram. Each team is asked to examine the tasks identified in the final step of the affinity diagram exercise and develop an executable workplan. The exercise forces the teams to identify not only the relationship between tasks in terms of content, but also in terms of timing sequence – in other words, which tasks may be performed concurrently versus tasks that must be performed sequentially. The result of this exercise is a process flowchart, in which all tasks necessary to achieve a goal (e.g. improvement of undergraduate civil engineering education) are charted in a form that may be executed.

As a final exercise, the teams are asked to use the techniques presented in a rough, "first-look" at their project. The primary objective of this exercise is to get the team members *talking* about the various components of their project. For example, how project components relate to each other, the types of data needed to analyze/design each component, and some (admittedly vague) ideas of the sequence in which the components must be completed. One advantage of doing this "first-look" during this class period is that the instructor is present to answer questions, give encouragement, and help the students apply the concepts just learned to their specific situation(s).

*e) An ability to identify, formulate and solve engineering problems*

An ability to identify, formulate and solve engineering problems is inherent to the course. As a new practicing engineer, one of a graduate's most challenging problems may be the lack of "givens". In academia, most of the information needed to solve a problem is given to the student. Once they graduate, finding the "givens" is sometimes more challenging than solving the problem at hand. The projects require that students go out and gather the information required for design. For example, they learn how to determine the zoning for an area, where to find floodplain information, where to find roadway functional classification information, and where to get topographical maps. Students learn to identify potential sources for contract documents, technical construction specifications and standard details. They therefore graduate with some idea of where to go for information, and how to use that information to solve the client's problem.

*f) An understanding of professional and ethical responsibility*

Capstone design courses offer a unique opportunity to learn about ethics in a realistic context. Typically, ethics is taught as a separate course, if it is taught at all. This has an advantage in that in-depth learning about ethics is facilitated. However, for a student to really understand how integral ethics is to engineering practice it has to be introduced as part of a project. In the real world engineers don't do ethics one day and design the next; therefore, students should have an opportunity to use ethics in the context of an engineering project. For example, if a student team is doing a drainage/hydraulics project it creates the opportunity to discuss how the project may affect adjacent properties. Development projects give an opportunity to discuss the implications of design in the community, and how the solution with the most profit may not be the best ethical decision. Students should be given the chance to defend their decision to a client who may not understand that the engineer's primary responsibility is to the public. This may be done as a role-playing exercise in their presentations (see g).

Because the University of Arkansas does not have a separate required ethics course in the engineering curriculum, an ethics unit is taught in Senior Design. The National Society of Professional Engineers' (NSPE) Code of Ethics is reviewed in class and the principles learned are applied to selected cases. The board game "The Ethics Challenge," developed by Lockheed-Martin, is used to facilitate discussion of ethical principles in a non-threatening environment. After an ethical foundation is built, the concepts learned in the unit are applied by the project teams to scenarios specific to their projects, which are developed with input from the consultants providing the projects. For students working on a flood control project, the instructor may compose a letter from an adjacent landowner expressing concern that the project might create drainage problems on their property and require them to respond. For a development project, students may be asked how they would handle it if a city employee offered to "fix" the permit process for a development if compensation were given. The key is to make the ethical dilemma relevant to their project work.

*g) An ability to communicate effectively*

As in a "real" project, students are required to make a presentation at the 50% design stage and at the final submittal. They must present and discuss their design procedures and decisions, and defend them. Area consultants, professors, representatives of city engineering departments, and anyone else available that can ask them good insightful questions is invited to attend their presentations. Role-playing may be used to give them some idea of what a presentation before a city council, planning commission, or other government agency is like. For example, the instructor may put on a bonnet and shawl and impersonate the hostile landowner next door to their project, and ask questions accordingly.

The whole Senior Design experience creates a laboratory for developing better communications skills. Learning to work as a team is a good way to learn to communicate effectively with others. They are also required to defend decisions in writing, as in the ethical dilemmas presented in f) above. They must turn in cost estimates, project budgets, and design calculations in a professional manner. In these ways, and by insisting on professionalism in all assignments turned in, students hone their communication skills.

*h) The broad education necessary to understand the impact of engineering solutions in a global/societal context*

Senior Design enables students to take the broad education provided by the engineering curriculum and apply it to a specific project. The exercises used to enhance communications and ethical skills also help students to understand the impact their decisions have on society. They also learn to defend those decisions from an ethical, professional viewpoint.

*i) A recognition of the need for and the ability to engage in life-long learning*

Even the most self-assured student realizes quickly in Senior Design that there is always more to learn. To solve the problems inherent to their projects, students must reach outside their experience and seek information and the knowledge of how to use it. This may be one of the greatest benefits of Senior Design.

Actually, as more and more states adopt continuing education requirements as a condition for maintenance of professional licenses, engineers will be forced to engage in life-long learning whether or not they realize its benefits.

*j) A knowledge of contemporary issues*

Engineering graduates must understand how contemporary engineering and societal issues affect the practice of civil engineering. Class discussions include how politics may affect design decisions and the effect of the economy on the profession. Articles in the NSPE publication *Engineering Times* are used to stimulate class discussion and to create assignments relating to current engineering issues. Another valuable tool is the National Society of Professional Engineer's U.S. Engineering Press Review, which is a synopsis of articles in various engineering publications. The articles are selected for their relevance to current engineering issues, and thus are a great source of material for class discussion.

*k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice*

Criterion 3-k sums up the intent of Senior Design rather well, as the ability to use techniques, skills, and modern engineering tools is necessary to complete the senior design project. All the attributes listed in a-j are necessary to accomplish this.

The design techniques learned in required courses in the civil engineering curriculum are applied to real projects in the senior design course. They are enhanced by the communications skills and professional viewpoint emphasized in the class. Engineering is addressed as a part of society, not just as individual, isolated projects. Modern engineering tools are heavily utilized in the completion of their projects. A project team may use AutoCAD or Microstation to produce their project plans, and may use any number of civil engineering software packages in the design process. However, if problems are encountered with compatibility of data with university computer resources, alternate methods may be used to complete the project, such as hand-drawing some of the design on the plan sheets. It is important that student projects not be significantly delayed by software problems that are beyond their control.

An important skill for civil engineers is the ability to write effective contract documents. In Senior Design, students learn how to use reference specifications to produce contract documents for their projects. Some of the reference specifications discussed in class and used for projects are from the Engineer's Joint Contract Documents Committee, the Corps of Engineers, the Navy, and other military/government organizations. Students learn what the various contract documents are for, and how to develop a technical specification for the construction of their project. As in ethics, students are better able to grasp the various concepts involved in both contract and technical specifications if they are applied to their projects.

## III. Conclusion

In summary, a well-planned capstone design course can be a catalyst for professional as well as technical development. To be fully effective, coordination with the local engineering community is invaluable. The instructor of the Senior Design course has been active with professional engineering organizations for a considerable length of time, and the contacts made have been invaluable in the implementing the methods described in this paper. The approach to teaching capstone design courses described here requires that faculty have considerable practical experience. If the combination of coordination with practitioners and practical experience is achieved, the outcomes described by Criterion 3 a-k are likely to result. Academia must rise to the challenge and continue to find new ways to enhance engineering education, resulting not only in better engineering graduates (the cake), but engineering departments that are well-prepared for the inevitable ABET 2000 review (the icing).

Bibliography

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MELISSA S. TOOLEY, PH.D., P.E.
Melissa S. Tooley earned her Ph.D. in civil engineering at the University of Arkansas in 1997 and joined the faculty at the University of Florida for one year. She is currently an Assistant Professor of Civil Engineering at the University of Arkansas. A former Arkansas Young Engineer of the Year, she had 8 years of consulting experience prior to returning to academia. Her graduate studies were supported by an Eisenhower Fellowship Grant, sponsored by the Federal Highway Administration.

KEVIN D. HALL, PH.D., P.E.
Kevin D. Hall earned his Ph.D. in civil engineering in 1993 from the University of Illinois at Urbana-Champaign and joined the faculty of the University of Arkansas, where he currently is an Associate Professor of Civil Engineering. He served two years with the U.S. Army Corps of Engineers prior to pursing graduate education. At the University of Arkansas, he has twice received the Texas Instruments Outstanding Researcher in Civil Engineering award.