ABET Assessment and Engaging Students in the Classroom Through Design Projects

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Abstract – One of the challenges of the Accreditation Board for Engineering and Technology (ABET) outcomes assessment process for Civil Engineering is the requirement to show "proficiency" in four major areas of the civil engineering profession. While there is no single best way to do this, this paper will present how we are attempting to do it at Western Kentucky University. Since the programs at WKU are new, we were able to create the curriculum from a blank slate, creating the types of classes and experiences that we felt were best for the student preparing for a career as a practicing engineer. With the importance of design in the curriculum and the need for assessment of both design and proficiency in four areas, this paper discusses how we combined those two requirements into a valuable experience for the student as well as an assessable product for the faculty. This paper will discuss how we have developed multi-course sequences in each of our chosen four areas of proficiency, and have utilized design projects in those course sequences to provide the student with significant opportunities to engage in both the technical and professional side of design. The projects revolve around actual projects within the community (as practical), strongly encourage the use of a professional engineering mentor, and integrate real-world issues such as budget, schedule, and environmental concerns. This paper will also present an in depth discussion of one of the design course sequences, an example of the student design project, and how the project was utilized in the ABET assessment process.

Keywords: ABET outcomes engagement student projects

INTRODUCTION

On November 7th, 8th, and 9th of 2004, Western Kentucky University (WKU) underwent its first ever EAC of ABET accreditation visit. This was both the beginning of one process and the end of another. It was the beginning of what is hoped will be a strong, dynamic, undergraduate engineering program focused on preparing graduates for careers as practicing engineers through project based education. It was the end of a 6 year process to develop these programs to both produce the desired graduate and to achieve accreditation. This paper will focus on one of the primary aspects of the accreditation process for civil engineering; that of demonstrating "proficiency in a minimum of four recognized major civil engineering areas". An example will be presented as to how we are demonstrating that proficiency as well as incorporating it into our outcomes assessment process through the engagement of students in design projects.

THE FOUR MAJOR AREAS AT WKU

One of the primary focuses of the engineering programs at WKU is to produce graduates to meet regional industrial needs. Early in the creation of the engineering programs, an assessment of those needs was performed to get a sense of what type of graduates would be most valuable to this region. In addition to this needs assessment, the Civil Engineering program formed an advisory board to further refine the type of CE graduates most needed. Based on this background research, the faculty and advisory board concluded that the major areas of the WKU CE program

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should be Construction, Geotechnical, Structural, and Hydraulics, with surveying being potentially a 5th area of focus in the future.

PROFICIENCY IN THE FOUR MAJOR AREAS

The term "proficiency" is used several times in the ABET criteria [ABET, 1]. While there exists a wide variety of definitions and applications of the word, the research performed regarding proficiency and student achievement led to the use of the definition and explanation of proficiency put forth by the American Society of Civil Engineers (ASCE) and their published commentary on the ABET Civil Engineering program criteria [ASCE, 2]. The following are quotes from that paper which helped to explain the intent of the word "proficiency":

"…the authors of the Program Criteria have used proficiency to be a measure by the profession of their expectations of the basic civil engineering knowledge imparted to the graduating civil engineer."

"Demonstration of proficiency implies an ability to accomplish something, such as design of a reinforced concrete beam under certain constraints or the application of statistics to the analysis of experimental data."

"The term proficiency expands the concept of understanding and ability to apply knowledge. Proficiency implies a depth of capability beyond the introductory level."

At this point in the program development process, the major areas had been defined and the term proficiency was relatively clear. The task now was to combine the two. The ASCE document also addressed this issue, but not nearly as in depth as it had for proficiency. The ASCE documented stated that while multiple courses in a single area was one way to try to demonstrate proficiency, it was not the only way. Initially, the concept of a 2 course sequence in each of the 4 areas was chosen as the method of demonstrating proficiency, which the ABET evaluator could determine simply by review of the required curriculum. However, as the first cohort of students made their way through the curriculum, the civil faculty felt that more needed to be done to show proficiency in the major areas, and that the project based focus of the curriculum was the best way to demonstrate proficiency. The final step in the process of demonstration of proficiency was to require the completion of a highly realistic engineering project into the 2nd course of each sequence in the four areas and to assess those projects to determine if the students were truly proficient. Once this decision was made, it was also clear that these same projects would be used to assess several of the ABET outcomes in Criterion 3, which provided for an effective, efficient way to address multiple aspects of the overall ABET Criteria.

ENGAGEMENT OF THE STUDENTS IN DESIGN PROJECTS

Table 1 shows samples of design projects integrated throughout the curriculum. The projects will progress in complexity as well as the amount of open-endedness involved as the student progresses through the curriculum. Ultimately, the projects in the 2nd course of a 2 course sequence will attempt to include most of the attributes associated with proficiency as outlined in the ASCE Commentary, as well as other items relevant to either the programmatic outcomes, the project itself, or both. For example, in the Freshman Experience course, students use the West Point Bridge Designer software as an introduction to design. They are able to see things like the fact that often a stronger bridge is also a more expensive bridge and see that design often includes tradeoffs, such as cost versus lifespan. While the project does not require much engineering analysis, it does begin to foster the basic concepts of design. As the students progress through the curriculum, they perform design projects that range from testing a material and reporting results in Strengths of Materials Lab to performing a full scale Geotechnical Engineering foundation study in Foundation Engineering.

In this process, the students are engaged in design through a progression of experiences throughout the curriculum, which guides them through a transformation from learner, observer, assistant, and ultimately practitioner [Lenoir, 5]). By being engaged, the students are active learners [Fink, 4] through hands on design experiences. They are learning instead of listening, doing instead of watching, and the faculty become engineering mentors instead of lecturers.

Table 1 – Samples of Civil Engineering Design Course Experiences Throughout the Curriculum

Course	Examples of Design and Project Activities	Year	Hr
CE 175 Freshman Experience in CE	The basics of engineering design are introduced through the West Point Bridge Designer Project (and other projects) where the students must adhere to specific standards and constraints, and consider non-technical issues such as economics. Students are exposed to ethics and professionalism through class assignments.	Fresh.	2
ME 331 Strengths of Materials Lab	The students are required to complete a project related to a materials problem or issue. They are required to set objectives, identify appropriate testing standards, design a series of experiments, and report results.	Soph	1
CE 410/411 Soil Mechanics & Lab	The students use technical tools and learn to model Geotechnical Engineering problems. They must develop project objectives, identify standards and constraints, and perform both technical and non-technical analysis of a retaining wall (or similar) project to meet specific client needs. A technical report is required.	Jr.	4
CE 412 Foundation Engineering	The student becomes proficient in this major area of CE by developing a project proposal and design budget, performs a feasibility study, and develops a design report to meet client needs. Students must also document their process through the use of an Engineering Science Notebook (ESN) which contains all technical analysis and data, and a Project Management Notebook (PMN), which documents meeting minutes, schedules, budget, etc.	Jr.	3
CE 370 Materials of Construction	The students are asked to perform an intuitive design with limited exposure to the requisite skills and knowledge for the project. They must design, test, and build a concrete structure to meet specific project objectives. Again, they must track their work with an ESN and PMN and incorporate all appropriate standards and constraints.	Jr.	3
CE 316 Equipment & Methods	Students become proficient in the Constructing Engineering area through advanced topical coverage in class and the completion of a design project where a construction process must be developed, priced, alternatives considered, processes optimized, and a final cost, schedule, and report completed.	Jr.	3
CE 461 Hydrology	Students begin to become proficient in hydrology and hydraulics as they must analyze a watershed and design a stormwater runoff system. Engineering standards and constraints are a vital part of the process as is consideration of non-technical issues in engineering	Sr.	3
CE 383 Structural Steel Design	Students become proficient in structural design through advanced topical coverage and the completion of a structural steel framing project that incorporates identification of objectives, data gathering, standards and constraints, engineering science and technical analysis, management, exploring of alternatives, iteration, and a final report.	Jr., Sr.	3
CE 498 Senior Project	Students become proficient in project execution. Students will select a design project that requires consideration of standards and constraints, engineering analysis, project management, involvement of different areas of civil engineering, and project execution.	Sr.	

CHALLENGES OF THE DESIGN PROJECTS

There are myriad challenges that must be addressed in order to effectively engage the students in this type of project based approach. While that is a paper topic in itself, a brief discussion is warranted here.

Perhaps the primary challenge is having faculty members qualified and willing to engage the students in these types of projects. At WKU, the engineering programs are undergraduate only, and the required qualifications of the faculty include industrial experience. In addition, the programs are not research based, but teaching based, and therefore the promotion and tenure criteria include requirements that the faculty must be active in the practice of engineering as consultants. It is the authors opinion and experience that the time spent working in the community and developing the necessary contacts such that real engineering projects are available is comparable to that required in performing research at a more traditional institution. The reality of having the students work on these projects is that the faculty must be actively involved, and it requires time. This is not a passive process of turning in homework to be graded by a teaching assistant. The faculty must have the professional background such that they can bring real engineering practice into the classroom as well as the time to work with the students in the development of the final product.

Another challenge is that of classroom time. While PBL has real advantages, the fact remains that information must be covered in the traditional classroom setting. It is vital that the faculty incorporate methods of delivering the necessary lecture content in an efficient way that allows sufficient classroom time when all the students are available to address issues related to their projects [Dettman, 3].

As stated above, an adequate discussion of this topic is a paper in itself, but it is clear that these challenges may be difficult if not impossible to overcome at a research institution, unless the university is willing to dedicate faculty positions to these types of engaging activities with the students.

THE DESIGN PROJECTS

This past academic year, the design projects in the four major areas consisted of the following:

Construction Area: CE 316 Construction Equipment and Methods – Design project consisted of developing earthwork quantities on a large local industrial project currently under construction, performing optimization calculations for multiple combinations of earthmoving equipment to determine the most efficient method of performing cuts and compacting engineered fill, determining the cost to perform the work including mobilization, de-mobilization, equipment cost, labor cost, profit, and overhead, and developing a construction schedule for the earthmoving operations. This project did utilize an actual project, which required the students to visit the site on multiple occasions, however the results were not used during construction.

Geotechnical Area: CE 412 Foundation Engineering – Design project consisted of a foundation design for fluidized bed combustor building for WKU. The building is a steel frame, masonry wall structure with a foot print of 50 feet by 50 feet and a height of 80 feet. The project required determining number and location of soil borings, development of a lab testing plan and performing some of the tests, development of design criteria for shallow and deep foundations, settlement analysis, impact of the foundations on a nearby retaining wall, pavement design for associated parking, and preparation of the design report. The project also included requests for additional information from the architect which was a request for uplift capacity of the caissons (which was the chosen method of foundation support for this project). This was an actual project and is currently under construction. The students developed a design report which was graded by the faculty member (including multiple opportunities for re-writes), and ultimately edited by the faculty member and submitted to the architect for construction.

Structural Area: CE 383 Structural Steel Design – Design project consisted of a framing design for a Walgreens store. The project consisted of determining loads, performing the structural analysis, sizing members, designing connections, and preparing construction documents. The results were not actually used during construction; however the students were able to see the steel erected and see and discuss the differences in their designs relative to the actual design.

Water Area: CE 461 Hydrology – Design project included the survey of an existing sinkhole, delineation of the watershed, development of the Curve Number for infiltration, determination of runoff quantity based on the 100 year storm, and development of a flood line elevation in the sinkhole, and preparation of both a written report and oral presentation. The final data will be submitted to the city of Bowling Green for input into their flood mapping data base. The city is using a GIS system, therefore the students also received an introduction to GIS and created a file that could be imported directly into the city database.

A significant amount of effort went into the development of the design experiences in the four areas so that all of the critical aspects of the design process would be satisfied in addition to demonstrating proficiency. Those critical aspects include the project based mission of the program, as well as the discussion of what design is in the ABET accreditation criteria as well as the ASCE commentary. The CE faculty are committed to the idea that none of these can be compromised at the expense of the other. While each faculty member has the freedom on their courses to develop their own criteria with regard to project requirements and grading policies, they must capture the essence of design as discussed in the mentioned literature and adhere to the following general outcomes of senior level design projects:

- Technical skills – Students will demonstrate the appropriate level of analytical skills and make use of appropriate technical tools in multiple areas of civil engineering
- Project Management – Students will be able to work effectively in teams, and will be able to effectively manage and track a project considering economics and schedule.
- Objectives, Standards and Constraints – Students will be able to determine the objectives of the problem at hand and will identify and incorporate the applicable standards and constraints.
- Communication – Students will be able to communicate their designs effectively in written format as well as professional presentations.
- Professionalism – Students will behave professionally and ethically, will produce professional documents, and will incorporate consideration of social and contemporary issues in their designs .
- Teamwork – Students will work in teams on the design projects and will be effective and productive team members.

Also, in addition to the expected deliverables of the final product which must include a written design report, the students must document all of their analysis in an Engineering Science Notebook and they must also track all time management (meeting minutes, action items for team members, schedule, etc.) in a Project Management Notebook which could be requested by the faculty member at any time for review and was required to be submitted with the final report. The students, as well as the faculty, found this very helpful in organizing and tracking data.

ASSESSMENT OF THE DESIGN PROJECTS

The overall criteria of what the design project should address lent itself very well to ABET assessment of the a-k criteria. The design project from one course could be used to assess at least 7 of the 11 a-k criteria. Table 2 shows the rubric developed to assign the overall aspects of the design project and Table 3 shows the rubric developed to assess the application of math, science, and engineering (ABET outcome a). Other rubrics were developed to assess written communication, oral presentations, and project management, however in the interest of space, they are not included in this paper but they will be shown during the conference presentation. The criteria for each rubric have been written such that a score of 3 represents a student who generally performs the required work correctly, with at most 1 or 2 minor procedural errors that impact the final result only slightly, which in the most general terms defines proficiency. Ultimately, the faculty member performing the assessment must determine if they feel that the work demonstrates proficiency.

Table 2 – Design Project Scoring Rubric

Objective	4 Exemplary	3 Proficient	2 Apprentice	1 Novice	Score
Identifying specific project objectives, standards, and constraints based on general project requirements	All important objectives, standards, and constraints are identified and clearly implemented	Most important objectives, standards, and constraints are identified and implemented with only minor deficiencies	Some objectives, standards, and constraints are identified with some deficiencies	Objectives, standards, and/or constraints not clearly identified or contain significant deficiencies	
Applying approriate civil engineering analysis	Correct application of all appropriate analysis techniques	Analysis generally correct with only minor procedural errors	Most analysis techniques correct, but contains significant math and/or procedural errors.	Incorrect techniques selected	
Considering the non-technical issues and incorporating them into the design	All significant non-technical issues identified and clearly considered in the design process	Most significant non-technical issues considered and incorporated into the design process	Some non-technical issues considered, some issues not considered or not clearly incorporated into the design process	Non technical issues either not considered or just mentioned without being considered in the design process	
Generating and analyzing alternative solutions	All appropriate alternatives are considered. If only 1 alternative is considered, a clear explanation is provided as to why no other alternatives considered	Most alternatives are considered. If any appropriate alternatives left out, they are the least feasible.	Only 1 acceptable solution is considered when other alternatives exist	The best alternative is not considered.	
Synthesizing all data and choosing the optimal solution based on evaluation of project criteria	Best solution is recommended based on stated criteria.	Reasonable solution is recommended; other alternatives could have been developed and analyzed.	Satisfactory solution is recommended; better solutions were available and should have been considered.	Only one solution considered; no optimization included; better solutions were available.	

Note: The descriptors given for the different levels are general targets for the achievement of the outcome. The evaluator should ultimately use his/her best judgment as to the appropriate level of achievement.

Table 3 – Rubric for Assessment of the Application of Math, Science, and Engineering

Objective	4 Exemplary	3 Proficient	2 Apprentice	1 Novice	Score
Physical Model	Applies correct concepts to formulate a model with no errors affecting the problem solution.	Applies correct concepts to formulate a model with no conceptual and only one or two minor procedural errors.	Applies correct concepts to formulate a model; solution is conceptually correct but contains several procedural errors.	Applies incorrect concepts to formulate a model or solution contains conceptual or procedural errors affecting the problem solution.	
Mathematical Analysis	Applies correct mathematical concepts to formulate a model with no errors affecting the problem solution.	Applies correct mathematical concepts to formulate a model with no conceptual and only one or two minor procedural errors.	Applies correct mathematical concepts to formulate a model; solution is conceptually correct but contains several procedural errors.	Applies incorrect mathematical concepts to formulate a model or solution contains conceptual or procedural errors affecting the problem solution.	
Final Result	Final result is correct and presented in the most appropriate format	Final result is correct, presentation of answer generally appropriate	Final result and/ or presentation reflect noticeable errors	Final result is incorrect, answer presented inappropriately	
Overall problem solving techniques	Solves problem using logical step-by-step and efficient procedure and obtains correct solution.	Solves problem using logical step-by-step procedure and obtains correct solution.	Solves problem using logical step-by-step procedure but makes minor procedural errors resulting in incorrect solution.	Solves problem without logical step-by-step procedure and makes procedural errors resulting in incorrect solution.	

Note: The descriptors given for the different levels are general targets for the achievement of the outcome. The evaluator should ultimately use his/her best judgment as to the appropriate level of achievement.

The first cohort of students graduated in May 2004 and provided a detailed look at the implementation of the process and the assessment. Overall, the faculty were pleased with the results. In the design projects completed in the 2nd course of the two course sequences, the students were generally performing at a level of proficient or better, according to both the rubrics as well as the perception of the faculty member in charge of the course. In some cases, the design projects were evaluated by faculty not involved in the course and there was good correlation of the rubric assessment between the faculty.

In addition to assessment by the faculty, a group of engineering practitioners were invited in to assess the design projects. The group included presidents of consulting firms, members of the state board of engineering licensure, chief engineers for the highway department, and others of a similar background and level of achievement. They used a simplified assessment tool which simply asked them to determine if the work was exceptional for a typical CE graduate, satisfactory, borderline, or unacceptable. In each case, the group tended to think the work was exceptional and was very impressed with the work done by the students. This same group also assessed some final exams, homework assignments, lab reports, and a written report on engineering ethics and came to a similar conclusion in each case; that the students work was generally exceptional. All of this data was documented, presented in the ABET Self Study, and reviewed by the CE program evaluator during the site visit.

While a great deal of information was obtained from the design projects in the 2nd course of the sequences, one of the overriding impressions was that the students are very adept at putting together very nice reports and that the quality of writing improved greatly in the team environment when they had more time to write and edit, as opposed to a lab report that must be completed in a week. With a sequence of written assignments due throughout the semester, the writing quality noticeably improved. Also, it was clear that the students were grasping the idea that the job of an engineer is not doing calculations all day. The majority of the time is spent writing reports and responding to requests for more information. With specific deadlines for portions of the projects, the students had to budget their time and quickly realized that they could not spend exorbitant amounts of time crunching numbers, but that they had to come up with a reasonable model of the problem, develop a solution while exploring a few alternatives, and move on to writing the report. While some may view the downplaying or simplifying of the analytical portion of the project as a negative, the fact is that this is what engineers do in practice. There are plenty of courses in the curriculum where the students can "flex" their analytical muscle, but the essence of this program is that students begin to understand what it is an engineering practitioner does on a day to day basis, and the overall perception is that the program has had early success in doing just that. As a side note, the CE program currently has a 100% pass rate on the FE exam for the first 2 graduating classes, which is a testament to their fundamental analytical skills.

THE GEOTECHNICAL DESIGN PROJECT SEQUENCE

The Geotechnical course sequence consists of CE 410 Soil Mechanics (and lab) and CE 412 Foundation Engineering. The first course of the sequence, CE 410, focuses on the analytical side and provides the students with the tools necessary for advanced study. They learn basic soil properties, soil classification, soil compaction, distribution of stress in soil masses, settlement, how soils generate strength, lateral earth pressure, and basic foundation design and slope stability. The 2nd course, CE 412, builds upon the first course and covers topics including the Geotechnical Engineering report, shallow foundation design, deep foundation design, advanced slope stability, and soil stabilization.

The design project in CE 410 for the first cohort of students was the development of lateral earth pressures for the design of a retaining wall. During the semester in which this course was taught, there was a project on campus that involved the construction of a retaining wall about 150 feet long and 15 feet tall. While the development of lateral earth pressures is not anything new for a first course in soil mechanics, the way the problem was presented and the expected results were. The assignment started with a letter from the architect to a Geotechnical Engineering firm (the students) stating that a retaining wall was to be built and they needed lateral earth pressures to provide to the structural engineer for design. Since the construction of the wall had started, they had a peek into the future to see some of the things that they needed to consider during the analysis process. For example, the wall was built within 30 feet of a building that was currently under construction, so they had to consider surcharge loads during the construction process such as crane loads, loads from the stockpiling of materials such as masonry units, and the

potential for loads from the building itself. Also, since the soil "loading" the wall was not yet there, they had to find out what type of soil was to be used as backfill, the compaction criteria, and whether the top of the backfill was to be landscaped or topped with a concrete deck. The final product was a letter to the architect providing the lateral earth pressures to be used by the structural engineer for design of the wall. During lecture, there was a discussion of two final items with regard to how the results should be presented. First, the stress diagram including all of the necessary loads was fairly complex. A discussion was held on how to simplify the diagram such that it was easy for the structural engineer to interpret and apply to his design. The students did a good job of simplifying the complex shape of the diagram into a more usable shape so that the forces could be easily calculated. In addition, a discussion of a factor of safety was held. The students ultimately had to determine the magnitude of the factor of safety and where it should be applied. As indicated in the assessment section of this paper, the students did a very good job of handling all of the variables and developing a sound report.

The design project in CE 412 was a larger scale, more complex project. Early in the semester, the students were provided with a request for a proposal from an architect for a fluidized bed combustor building, built of structural steel frame and masonry walls, with a footprint of 50 feet by 50 feet and a height of 80 feet. They were to provide a proposal and cost estimate for a subsurface investigation, laboratory testing, and preparation of a final report. This was an actual project going on concurrently with the class, and the faculty member teaching the class was the engineer performing the Geotechnical Investigation for the project, so the students were able to perform, side by side, the same tasks as the actual project engineer so they could compare their design with the actual design. During the course of the semester, the students observed the drilling of the soil boring, proposed a series of laboratory tests considering what was needed and the available budget given prices for each test, analyzed the results, and developed foundation design options for the project. They also were assigned the task of performing a pavement design for the parking area which required them to draw on knowledge from their Transportation Engineering course as well. Also included in the project were 2 different requests for additional information from the architect, which included a shallow foundation design for a small coal storage building and uplift capacity of the deep foundation system as the wind loads governed the design. Ultimately, the students developed a full scale Geotechnical report and gained first hand experience with a real project on what it is like to be a Geotechnical Engineer.

Most of the student comments revolved around the fact that they were not aware of how much writing is involved in engineering. In addition, they were surprised at the challenge and expense of tracking a design budget, as they were required to document the time they spent working on the project and, given real world billable rates for practicing engineers, develop a final cost. As expected, they spent a considerable amount of time on the project, and were able to grasp the efficiency they must develop in preparing engineering reports to try to stay within a budget.

All in all, the students gained a great deal of practical experience during the course of the project. Of course, it is difficult to incorporate an actual project each semester as these opportunities do not come up all of the time, but if the faculty member has the proper experience, they can develop similar experiences for their students.

CONCLUSION

The CE faculty at WKU are confident that through the engagement of students in real world projects, they are better prepared for entry level engineering positions than they would be in a more traditional lecture environment. While some of the senior level design courses may be somewhat less analytical than comparable courses at other institutions, they are much closer to real design experiences. Engineers are not simply mathematicians as the calculations are just the beginning. They must be effective writers, be able to track budgets, be efficient in their work, and they must learn how to execute a project from beginning to end. All of these tasks are integral parts of an engineers job in many cases. Through these projects, not only do the students gain this knowledge, but the faculty are able to utilize the data as very effective assessment tools to demonstrate both proficiency and achievement of outcomes as defined by ABET.

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