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A Novel Approach to meet the Expectation of Culminating Design Experience

Dr. Shashi S. Marikunte, Pennsylvania State University, Harrisburg, The Capital College

Shashi S. Marikunte is an Associate Teaching Professor of Civil Engineering and Acting Chair at The Pennsylvania State University, Middletown, Pennsylvania. He serves as the Program Evaluator (PEV) for ABET and also the ABET Coordinator for the Civil Engineering (CE) as well as Structural Design and Construction Engineering Technology (SDCET) program.

A Novel Approach to meet the Expectation of Culminating Design Experience

Abstract

The Engineering Accreditation Commission (EAC) of ABET requires that the program curriculum provides a culminating design experience that prepares students for engineering practice. Emphasis is placed on how this experience is based upon the knowledge and skills acquired in earlier coursework and incorporates appropriate engineering standards and multiple design constraints. In many Civil Engineering programs, capstone projects are associated with an advanced course with emphasis on one concentration area. Even though students may incorporate components outside of their concentration areas, it is rather minimal. This narrows student's culminating design experience to that specific concentration area. However, a better approach may be to broaden this culminating experience to go beyond one concentration area. At our program, we formulated a novel way for students to work on an inter-disciplinary project in civil engineering. Students from four concentration areas within civil engineering (structures, construction, transportation, and environmental engineering) were offered an opportunity to work together in small groups on an active or proposed project that included components from all four concentration areas. Placing emphasis on all four concentration areas provided an improved culminating design experience. Student groups diligently worked on this project in true competition style, to incorporate changes through value engineering, sustainability, energy efficiency, and other modern tools to improve the functionality, or other aspects of the project. Students had the opportunity to review actual construction drawings and work in inter-disciplinary teams to incorporate changes. Students presented their final project in front of a mixed audience that included students, faculty, family, and professionals during the Capstone Design Conference. A team consisting of faculty and industrial advisory board members evaluated the communication and technical skills of students during this conference. A rubric with emphasis on incorporating appropriate engineering standards and multiple design constraints was used to assess the group performance. Confidential peer-reviews were then used to assess the performance and contribution of individual members, and their interaction with other members of the group. In addition to broadening student learning, this approach was also valuable to assess ABET student outcomes that are difficult to assess in the traditional class setting. This paper presents the beneficial effects of a broader approach to providing a culminative design experience.

Introduction

Engineering education across the United States, predominantly culminate in a capstone design course to meet the ABET requirements. However, the way capstone design projects are offered or conducted varies. In some programs, the capstone project is embedded in a course for one semester, or a sequence of courses offered over two semesters. Some programs offer flexible capstone class, and the project is either assigned or students may have several projects to select from. Capstone courses are also widely used for the assessment of Student Outcomes (SOs) due to the wealth of information one can collect. Many of the capstone projects may involve real-world problems and multidisciplinary teams. While multidisciplinary projects are easy to achieve in some areas of engineering, it has been a challenge for civil engineering projects. Even working on a project involving multiple concentration areas within civil engineering is a challenge due to the way courses are offered at many universities [1 – 9].

Students in our civil engineering program have the option to focus on four different concentration areas: structures, construction, transportation, and environmental engineering. Each concentration area has a specific capstone class. This is typical in many universities. Students enrolled in those classes work on a capstone project which focuses on their concentration areas. This approach will provide minimal or no exposure to other concentration areas. To overcome this, our program came up with a novel idea to provide opportunities for students from different capstone courses to work together. The project was selected in a way that included all concentration areas to provide real-life experience, like working in a civil engineering company. The primary objective of this approach was to challenge students to work in multidisciplinary teams and include best practices in the industry while enhancing their technical as well as communication skills. We merged students from four concentration areas of civil engineering (structures, construction, transportation, and environmental engineering) to work in a small group of up to eight students. The project assigned included all concentration areas and students were informed to place emphasis on all four concentration areas to enhance culminating design experience. Some of the example projects students worked in the past few years include building projects for a university that includes classroom and laboratory facilities; building project for a university that includes student services facilities and an auditorium; indoor sports complex in a local community; and ash recycling facility for a local township. A sample project along with the scope of the required guidelines provided below:

Sample Project

One of the project students recently worked on was a building consisting of teaching and research space at a university. This building was under construction when students were working on the project. The specifications, geotechnical reports, and drawings for the original proposed building were provided to students. The objective was to work as a team designing critical components, planning and estimating including cost estimate, and to address transportation needs of the university due to this new addition. Students had the flexibility to incorporate innovative ideas that will add value to the building. While bringing down the cost of the project was encouraged, it was one of the many factors that students were asked to consider while making the project functional and efficient. Students were provided with clear guidelines and requirements as well as the rubric used for grading.

Group Formation

Group formation started with identifying leaders who could formulate a team consisting of members from all concentration areas. The group selection was not random, and they had the option to join the group they were interested in. Exceptions were made when there was an imbalance in student enrollments in each concentration area. All members of the group were expected to not only focus on their concentration area but also contribute to the overall project. The group leader was responsible for coordinating the tasks and making sure they are completed on time. It was also the responsibility of the group leader to regularly organize meetings and report any personnel issues.

Project Requirement

- One of the main components of the project was to consider value engineering, sustainability, energy efficiency, and other modern tools to improve functionality, or other aspects of the proposed project. Students were informed to include all the options that were considered and the justification for the proposed changes/improvements.
- An interim report (one per group) along with the progress of the project was due mid semester. This short report (3 – 5 pages) highlighted the proposed recommendation along with the status of the project. Guidelines were provided by the technical writing experts from the Learning Center during writing workshop.
- A final report was due at the end of the semester. It included all the tasks completed along with detailed calculations and drawings.

Expectations:

There were two components for the project: required component; and value engineering component. All groups were required to perform the same tasks (Ex: analysis and design of system or members) under the required component. Value engineering included proposed changes to improve the functionality or other aspects of the proposed project. It was extremely important that students justify these improvements during the oral presentation to reviewers consisting of faculty as well as the advisory board members. The following guidelines were provided to make sure students were aware of the expectations for each concentration area as well as the overall improvement of the project. The project served as a basis to assess ABET Student Outcome 2 - An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. Even though the project was a group work, a peer-review process was established to assess individual performance.

- The structural design component involved identifying critical members and designing them to meet the latest code requirements. Students were required to design the project in accordance with the latest building codes (Ex: IBC, ASCE 7, ACI 318 and/or AISC), in addition to compliance with specific owner's requirements.
- The construction component involved estimating the original building and the project addition. The scheduling process involved preparing a Gantt chart to show all the activities and durations of the project. The value engineering process was applicable to the design addition only. Quantifying the effect of value engineering on LEED credentials was also part of the requirement. The following software programs were used throughout the construction design process to complete all the necessary items listed above: Microsoft tools (Excel, Word, PPT), AutoCAD, Revit, PlanGrid, RSMeans on-line, P6 – Primavera, and PDF.

- The transportation component involved determining the impact of the new facility in terms of traffic and transportation. This involved analyzing and forecasting the traffic and transportation around the project, parking space requirements, design of driveway according to the National Cooperative Highway Research Program (NCHRP) guidelines, conducting a warrant analysis for intersections around the campus and suggesting recommendations to improve traffic operations if needed. Additional requirements were to determine the Level of Service (LOS) on the roadways around the campus using Highway Capacity Manual (HCM) procedure as well as using Highway Capacity Software (HCS).
- The environmental component included analyzing the project area for stormwater drainage system, rainwater collection system, and other areas of significance.

Rubrics to Evaluate Capstone Design Project

A rubric with emphasis on incorporating appropriate engineering standards and multiple design constraints was used to assess the group. The guidelines along with the rubrics provided ensured a culminating design experience. The rubric for the culminating design experience is presented in Table 1. The performance indicators developed enabled us to ensure all concentration areas are adequately covered in the project.

Table 1. Rubric to Evaluate Capstone Project's Culminating Design Experience.

Performance Indicators	Exemplary (4)	Satisfactory (3)	Developing (2)	Unsatisfactory (1)
Adherence to Engineering Standards	Demonstrates comprehensive application of relevant civil engineering standards across all disciplines (e.g., AISC, ACI, AASHTO, PMI). All designs and plans fully comply with safety, load bearing, accessibility, and building construction requirements.	Apply relevant standards with minor deviations. Most designs and plans comply with safety, load bearing, accessibility, and building construction requirements.	Shows basic understanding of standards. Some designs and plans comply with safety, load bearing, accessibility, and building construction requirements.	Lacks understanding of relevant standards. Designs and plans do not comply with safety, load bearing, accessibility, and building construction requirements.
Identification and Analysis of Design Constraints	Identifies and analyzes constraints such as material properties, traffic flow, environmental impact, budget, and resource availability. Proposes innovative solutions to effectively address these constraints.	Identifies and analyzes most relevant constraints. Proposes practical solutions to address these constraints.	Identifies some relevant constraints with basic analysis. Solutions address constraints but lack innovation.	Fails to identify or analyze relevant constraints. Solutions do not effectively address constraints.

Evaluation of Solution Processes	Evaluates the design and project management processes by comparing multiple alternative approaches (e.g., different materials, structural systems, traffic management strategies, value engineering techniques). Justifies chosen methods with clear advantages and potential drawbacks.	Evaluates the design and project management processes with some comparison of alternative approaches. Provides justification for chosen methods.	Provides limited evaluation of the design and project management processes. Comparison of alternative approaches is minimal.	Does not evaluate the design and project management processes or compare alternative approaches. Lacks justification for chosen methods.
Identify Design Constraints and Develop Solutions to Overcome Them	Identifies all relevant design constraints across all disciplines with clear understanding and insight. Develops innovative and effective solutions that comprehensively address all constraints.	Identifies most relevant design constraints in all disciplines with good understanding. Develop effective solutions that address most constraints.	Identifies some relevant design constraints but misses key aspects in one or more areas. Develop solutions that address some constraints but are incomplete.	Fails to identify relevant design constraints or shows poor understanding in all disciplines. Develop solutions that fail to address key constraints or are ineffective.
Apply Relevant Mathematical and Scientific Principles to Define Engineering Problems	Apply mathematical and scientific principles accurately and effectively to formulate complex engineering problems in all disciplines. Demonstrates deep understanding of underlying principles and their applications.	Apply principles accurately to formulate engineering problems in all disciplines, with minor errors. Demonstrates good understanding of principles and their applications.	Apply principles with some errors or omissions in formulating engineering problems in one or more areas. Demonstrates basic understanding of principles but lacks depth.	Fails to apply principles accurately, leading to incorrect problem formulation in all disciplines. Demonstrates poor understanding of principles and their applications.
Apply Standard Principles and Perform Calculations	Performs calculations accurately with no errors in context with all disciplines. Apply standard engineering principles accurately and effectively.	Performs calculations accurately with minor errors in contexts with all disciplines. Apply standard principles accurately with minor errors.	Performs calculations with some errors that do not significantly affect results in one or more areas. Apply standard principles with some errors or omissions.	Performs calculations with significant errors that affect results in contexts with all disciplines. Fails to apply standard principles accurately.

Evaluate the Solution Process in Comparison to Alternative Methods	Thoroughly evaluates multiple alternative approaches, considering all relevant factors in all disciplines. Provides clear and compelling justification for chosen approach based on thorough evaluation.	Evaluates alternative approaches, considering most relevant factors in all disciplines. Provides good justification for chosen approach based on evaluation.	Evaluates some alternative approaches but misses key factors in one or more areas. Provides some justification for chosen approach but lacks depth.	Fails to evaluate alternative approaches or consider few factors in all disciplines. Provides weak or no justification for the chosen approach.
Report Writing	Report is well-organized, clear, and concise with logical flow, covering all disciplines. Includes comprehensive and accurate technical content. Effectively uses visuals (graphs, charts, diagrams) to enhance understanding. The report is free of grammatical errors and uses professional language.	The report is organized and clear with minor issues in flow, covering all disciplines. Includes accurate technical content with minor omissions. Uses visuals to support content but with minor issues. The report has minor grammatical errors and uses mostly professional language.	The report is somewhat organized but lacks clarity or logical flow in one or more areas. Includes some technical content but with errors or omissions. Uses visuals but they are not well-integrated or effective. The report has some grammatical errors and inconsistent language.	The report is poorly organized and unclear, lacking coverage in all disciplines. Lacks accurate technical content. Fails to use visuals effectively or at all. The report has significant grammatical errors and unprofessional language.

Oral Presentation

ABET Student Outcome – 3, requires students to possess an ability to communicate effectively with a range of audiences. Groups were informed to prepare their presentation with the idea that they are addressing a committee that consists of faculty members and industrial advisory board members with different technical expertise. The presentation was expected to convince the committee of the technical adequacy of their design and merits of their proposed changes/improvements and communicate with the general audience. It was the group leader's responsibility to make sure that each member of the group had adequate (equal) time for presentation. Each individual member of the group was evaluated for their presentation skills. The assessment was based on individual performance and not group performance. The rubric for evaluation of student's presentations is presented in Table 2.

Table 2. Rubric for Evaluation of Student's Presentations

Evaluation of Presentation	Rating Scale									
	1	2	3	4	5	6	7	8	9	10
Organization										
Visual Aids										
Time Management										
Technical Content										
Creative Thinking										
Communication Skills										
Teamwork										

Final Report

The final report was the culmination of the group's activities in the capstone design. Groups were informed that it must stand on its own merits as a document being submitted to an engineering committee who will review the technical adequacy of the project. The report was expected to address all the requirements of the project and must conform to the specifications. The report was expected to include the alternative approaches that were considered and justify the approach selected along with spreadsheets and computer outputs, if any, accompanied by simple calculations. The changes to the initial proposal needed were to be included in the final report. It is important to pay attention to the quality as well as quantity. The project was graded for technical writing skills, technical content, quality of work, innovative approach, cost savings and other benefits, and energy efficiency initiatives using the rubric presented in Table 1.

In addition to the above, there was a confidential peer-review of the group members. Since this was a group project, individual members' performance was evaluated for contribution, meeting deadlines, quality of work, providing and receiving feedback, and ability to work independently. Peer-reviews were kept confidential and were not revealed to members in the group. The rubric used for peer-review of individual performance is presented in Table 3.

Table 3. Peer-review of Individual Performance

Performance Evaluation	Rating Scale				
	1	2	3	4	5
Showing up for meetings					
Meeting assignment deadlines					
Quality of work					
Providing/Receiving feedback					
Ability to work independently					

Student Outcome assessment

In addition to evaluating the course for the culminating experience the following ABET Student Outcomes (SOs) were assessed.

Outcome 2 – An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economical factors. Table 4 presents the rubric used for assessing Student Outcome 2. The following system was used to rate each performance indicator based on students' performance:

Scale	**Exemplary**	**Satisfactory**	**Developing**	**Unsatisfactory**
Performance (%)	90 - 100	80 - 89	70 - 79	69 and below
Considered "Acceptable" at the program level	Yes	Yes	No	No

Figure 1 presents the assessment results. While there are some fluctuations, the assessment results show that students performed well. Covid_19 skewed the results slightly in Spring 2022.

Outcome 3: An ability to communicate effectively with a range of audiences. Table 5 presents the rubrics used for assessing Student Outcome 3. Figure 2 presents the assessment results. While there are some fluctuations, the assessment results show that students performed well. the individual performance used to evaluate communication skills were not impacted by Covid_19

Table 4. Rubrics for Student Outcome 2

Student Outcome 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.				
Performance Indicators	**Exemplary (4)**	**Satisfactory (3)**	**Developing (2)**	**Unsatisfactory (1)**
1. Develop a design strategy to meet public health, safety, and welfare.	Always develop a design strategy to meet public health, safety, and welfare.	Often develop a design strategy to meet public health, safety, and welfare.	Sometimes develop a design strategy to meet public health, safety, and welfare.	Rarely develop a design strategy to meet public health, safety, and welfare.
2. Develop a holistic solution to meet global and cultural factors.	Always develop a holistic solution to meet global and cultural factors.	Often develop a holistic solution to meet global and cultural factors.	Sometimes develop a holistic solution to meet global and cultural factors.	Rarely develop a holistic solution to meet global and cultural factors.

3. Apply engineering design to meet social, environmental, and economic factors.	Always apply engineering design to meet social, environmental, and economic factors.	Often apply engineering design to meet social, environmental, and economic factors.	Sometimes apply engineering design to meet social, environmental, and economic factors.	Rarely apply engineering design to meet social, environmental, and economic factors.

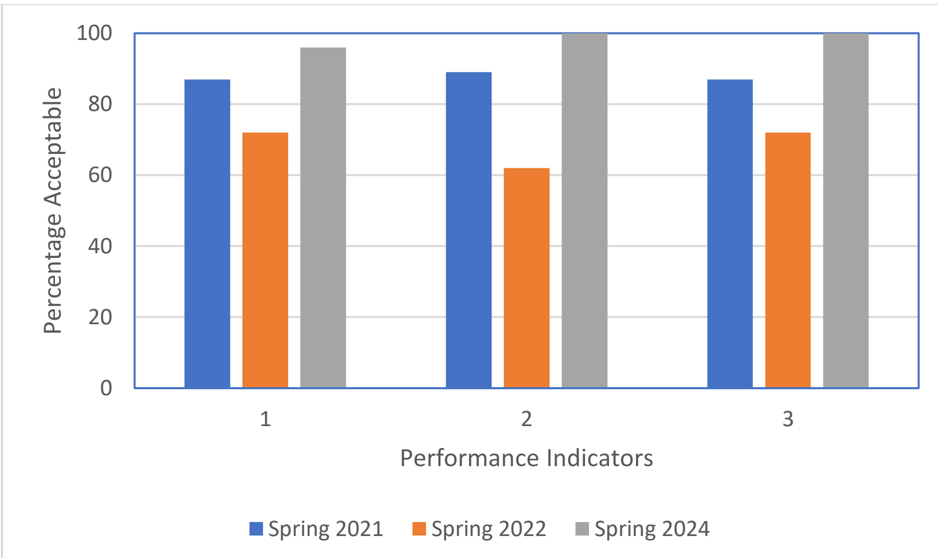

Figure 1. Percentage of Students Meeting Expected Student Outcome 2

Table 5. Rubric for Student Outcome Assessment 3

Student Outcome 3: An ability to communicate effectively with a range of audiences.				
Performance Indicators	**Exemplary (4)**	**Satisfactory (3)**	**Developing (2)**	**Unsatisfactory (1)**
1. Demonstrate technical writing ability	Always write organized and readable technical reports or proposals	Often write organized and readable technical reports or proposals	Sometimes write organized and readable technical reports or proposals	Rarely write organized or readable technical reports or proposals
2. Deliver oral presentations	Always deliver cogent oral presentations	Often deliver cogent oral presentations	Sometimes deliver cogent oral presentations	Rarely deliver cogent oral presentations

3. Explain and discuss technical issues	Always provide clear explanations and meaningful discussions on technical issues	Often provide clear explanations and meaningful discussions on technical issues	Sometimes provide clear explanations and meaningful discussions on technical issues	Rarely provide clear explanations or meaningful discussions on technical issues

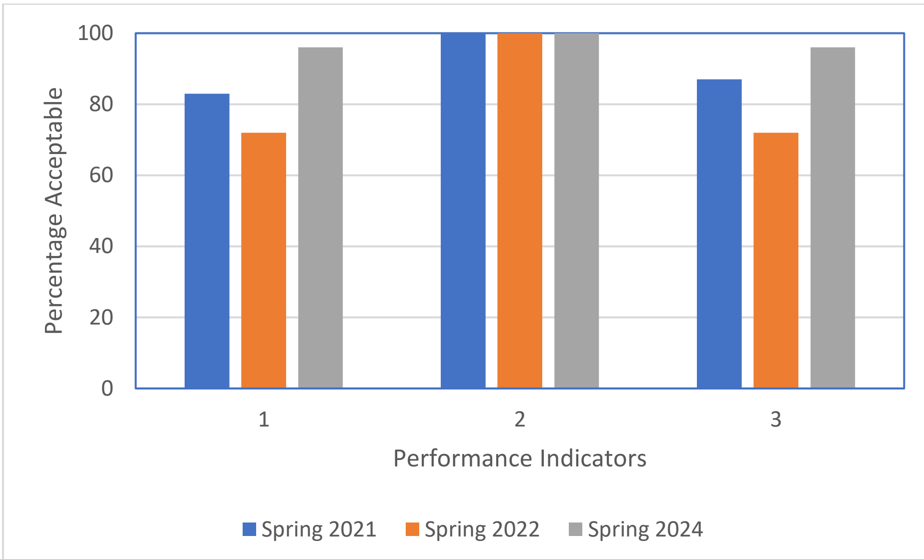

Figure 2. Percentage of Students Meeting Expected Student Outcome 3

Summary and Conclusion

The Capstone design project was offered in a novel way to use the traditional course offering yet provides an opportunity for students to work on an inter-disciplinary project in civil engineering with emphasis on all concentration areas. This provided a unique opportunity for students from four concentration areas within civil engineering (structures, construction, transportation, and environmental engineering) to work together in small groups on an active or proposed project that included components from all three concentration areas. The approach used is like what students expect once they start their professional career. The expectation was to provide students with a culminating design experience that prepares students for engineering practice. Based on the response received from students and the industrial advisory board members who evaluated student performance, the approach was very effective in enhancing student learning. The capstone project also served as an important tool to assess ABET Student Outcomes.

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