Features of a Robust, Real-World Industry-Project Based Capstone Senior Design Course in Mechanical Engineering for Undergraduates

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Abstract

The Senior Design Project Course in Mechanical Engineering at the University of Wisconsin-Platteville serves as a capstone course for undergraduates in their final semester. The course enables students to acquire a capstone design experience through real-world industry projects. Students work in teams of four to six members on each industry based project. To provide the capstone experience, the course needs to have clearly identified goals and objectives, appropriately planned content, and effectively managed teaching/assessment of students' learning and application of learnt content to their projects. This paper addresses detailed aspects of providing the capstone experience in a robust manner. Specific goals and objectives, content topics, and course administering and management tools to provide a robust capstone design experience are discussed. Examples are provided in the context of robustness which enables minimizing the effect of variables on outcomes such as teaching, learning, and assessment.

Keywords

Capstone Design Process Robust Mechanical

Introduction

The Mechanical Engineering program at the University of Wisconsin-Platteville is geared towards the goal of graduating mechanical engineers to be "industry-ready". "Industry-ready" is understood in this context as enabling students to have the necessary background and outlook to quickly and effectively adapt to engineering activities upon graduation. The Senior Design Project course that students take in their final semester before graduation provides the capstone design experience that is necessary to achieve this goal. The course is planned around team-based real-world industry projects and serves as a means to integrate several goals and objectives of the program in one single course at the most appropriate time close to graduation. To provide the capstone experience, the course needs to have clearly identified goals and objectives, appropriately planned content, and effectively managed teaching/assessment of students' learning and application of learnt content to their projects. This paper addresses detailed aspects of providing the capstone experience in a robust manner. Specific goals and objectives, content topics, and course administering and management tools to provide a robust capstone design experience are discussed. Examples are provided in the context of robustness which enables minimizing the effect of variables on outcomes such as course implementation, student learning, and assessment. Examples include design process models, industry projects, management content such as engineering ethics, personality types, etc., learning/assessment methods, and documentation.

Robustness and its Application to the Senior Design Project Course

In a general sense, robustness is the quality of insensitiveness to variations in achieving goals or results. Robust engineering for example is qualitatively the same and is accomplished through specific engineering tools such as successful execution of P-Diagrams[2], Design of Experiments etc. The focus of robustness in this paper though is regarding achieving it in providing the necessary education and in enabling the students to learn the expected outcomes. The means adopted to achieve this robust education in the course are described in this paper.

Goals and Objectives of the Senior Design Project Course

The main goal of the Senior Design Project course is to provide students with a design experience that is typical of what they will encounter in industry. The experience is provided within the framework of educational requirements. All of the projects are sponsored by external sources, typically industry. The projects are *real* projects. Satisfying customers' expectations is an important means of achieving the main goal of the course.

The specific objectives are for the students to:

Obj1. Engage in creative engineering.
Obj2. Apply fundamental principles to design.
Obj3. Learn and participate in the dynamics of team effort.
Obj4. Critically consider design alternatives.
Obj5. Consider scientific, technological, social, ethical, economic, and environmental aspects of engineering as warranted.
Obj6. Cultivate a life-long learning approach and involve in contemporary issues
Obj7. Complete the project within time and budget constraints.
Obj8. Practice oral and written communication skills.

Summary of how the Course is conducted over the Semester

The administration of the 4-month long course can be summarized as follows. The *italic* words in each task below are used as brief sub-titles later in the paper and described further.

1. *Gather projects* ahead of the beginning of class
2. *Prepare preliminary documentation* to share information with students regarding the projects, formation of teams, request by teams of projects they are interested in, assignment of projects to each team, and short-term and long-term formal tasks/deliverables by the teams.
3. *Initiate the Projects* by describing the projects, forming the teams, having teams identify their project choices, and assigning projects.
4. *Undertake field trips* to companies to understand the problem better
5. *Enable learning and Implementation of the Design Process and Methods*
6. *Ensure that the goals and objectives of the course are achieved* through the capstone design experience

Unlike most other courses in undergraduate engineering education, an industry-sponsored course has some content and logistics differ each semester due to obviously the assignment of different projects. It is obvious that this difference introduces variations that are above and beyond the normal variations in traditional classes. Robust education methods are the means to help achieve the goals and objectives under the presence of all these variations. These methods are described while discussing the tasks listed above in more detail below.

Gather Projects

Weeks before the beginning of class, it is necessary to contact companies to solicit potential projects. Selecting a list of projects that fits the design process and technical expectations, having the right balance of new and regular sponsors, and having the right balance in the nature of projects contribute to the robustness of the gathered projects. It often takes knowledge and experience with industry to gather such a robust list of projects. During the process of soliciting projects, information that is common to all sponsors must be provided to them to minimize avoiding the unnecessary variable of the same common questions being asked by the sponsors over a period of time which can be saved. Examples of such common information are the duration of the project, funding, deliverables that can be expected, key dates, and sponsor participation requirements.

Prepare Preliminary Documentation

The importance of planning and preparing the preliminary documentation necessary to inform the students about the goals and objectives of the project, the course of study, and details of the available projects as well to as to form the teams, and to have the teams identify the projects they like the most cannot be underemphasized. If this task is planned and documented properly, it is possible to form the teams, assign projects to each team, and even start off on field trips to the sponsors' facilities by the end of the first week of classes. The documentation that is planned and prepared includes the following:

- Course of Study that includes the goals and objectives of the course, description on the team-based nature of work on industry-sponsored projects, grading policy, and major deliverables for the course such as Weekly Progress Reports, Interim Report and Presentation, Project Manager evaluations, and Final Report and Presentation
- Template of the Weekly Progress Report
- Template for evaluation of Project Manager by team members
- Template for evaluation of team members by the Project Manager
- A list of numbered projects with title, company name, and location
- A package of detailed information about each project to each team
- A "bidding form" to each team to select their most favorite project choices
- A student schedule form to each student which will help in planning trips and arranging team meetings outside of class

It should be noted that if this front-loaded task is not well planned, documented, and shared with students in the first week of classes, a big price is paid in terms of lost time and degradation of control necessary from the outset to manage and achieve goals and objectives. The instructor "leading by example" will also be marginalized and will become an uphill task to do so further on if this task is not well executed. From the perspective of robustness, not executing this key step well can only result in a myriad of variables in terms of ineffective communication with and for the students and their teams.

Initiate the Projects

The following steps are required to initiate the projects:

- Go over the Course of Study on the first class meeting
- Give a copy of the summary list of projects and go over the same
- Go over the description of projects in a brisk manner because there is a lot to get done on the first meeting of class
- Ask the students to form the teams with required number of students in each team (This is a good time to let the students know that the process of making decisions in any design project environment just started!!)
- Give the project description package and bidding form to each team
- Ask the team to discuss the projects and complete and return the bidding form listing their most favorite projects before the end of the first day of class
- Give the student schedule form for students to complete and return before the end of the first day of class
- Go over the bidding form from each team after class and choose a specific project to each team
- Make necessary documentation of the chosen project for each student of each team
- Assign the chosen project to each team and distribute necessary documentation to each student

The robustness achieved by initiating the projects in the above manner minimizes ineffective communication about projects and avoids delays in team formation and project assignments. Successfully initiating the projects as described above sets the tone for the entire semester including kicking off the idea of the instructor "leading by example".

Undertake Field Trips

Field trips to various company sponsors' locations to better understand their project is a time consuming but important task in design projects. Students are given a checklist of things they need to do in preparing for the field trip. Some items on the checklist include contact information particulars, camera/video recorder, and list of questions about the project for the sponsor to answer. Once again, the checklist document provides the robustness needed to minimize variation in both the quantity and quality of gathered information about the projects by each team. The field trips are not only instructive to the students but to the instructor as well.

Enable Learning and Implementation of the Design Process and Methods

This task forms the core of the Senior Design Project course. First, it is extremely important to select a model of design process and methods that is robust in terms of its ability to most practical and adoptable to any project. The model chosen is a modified version of the Symmetrical Problem Solution Model by Nigel Cross[1] is adopted. The model is shown in Fig 1. The model shows six major design process steps. Note the iterative nature of design as identified by the two way arrows of communication between any two steps of the design process. The steps are described next. It should be noted that students apply every step of the design process and the methods within it to their respective projects right after learning it.

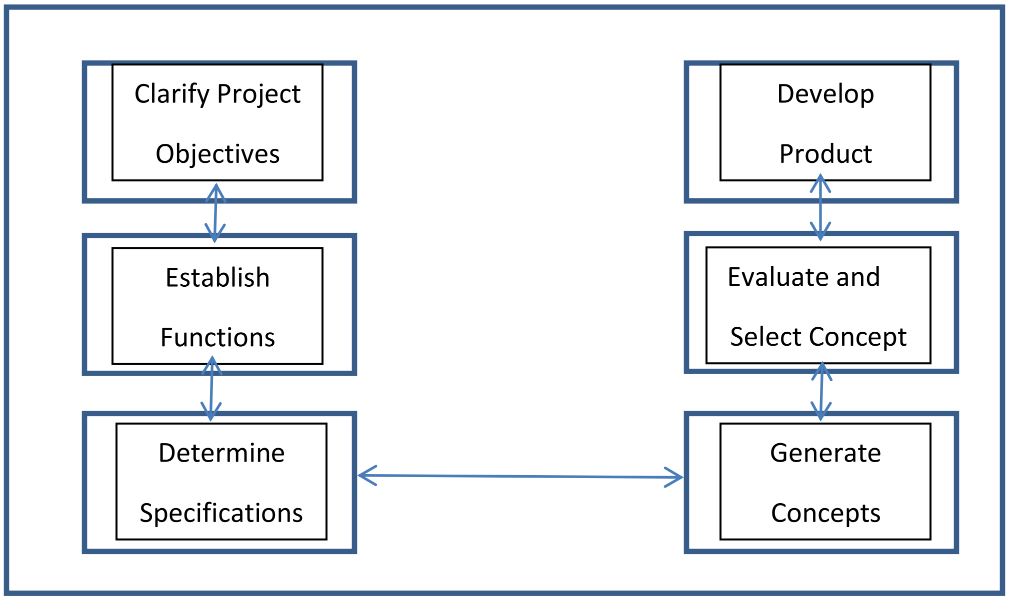


Fig. 1 Modified Symmetrical Problem Solution Model of Design Process

<u>Clarify Project Objectives</u>

This important step involves identifying the customers' goals or objectives for the project. Project goals or objectives are customer requirements that are qualitative. Examples are low cost, high efficiency, and ease of assembly. It should be recognized that anyone who interfaces with the product at any time in its life from creation to retirement is a potential customer. Customer requirements must also be weighted for their importance. The weights are also based on customers' inputs. An objective tree is used as the design method to document the objectives and their weights. The template of an Objectives Tree is shown in Figure 2. The lowest level objectives in the tree are the explicit objectives that any final project solution must meet. Students are asked to first come up with their individual version of customer requirements before they work together to come with a team version that is documented as an objectives tree. This process achieves objectives Obj1, Obj3, and Obj7 of engaging in creative engineering, participating in team effort, and communicating.

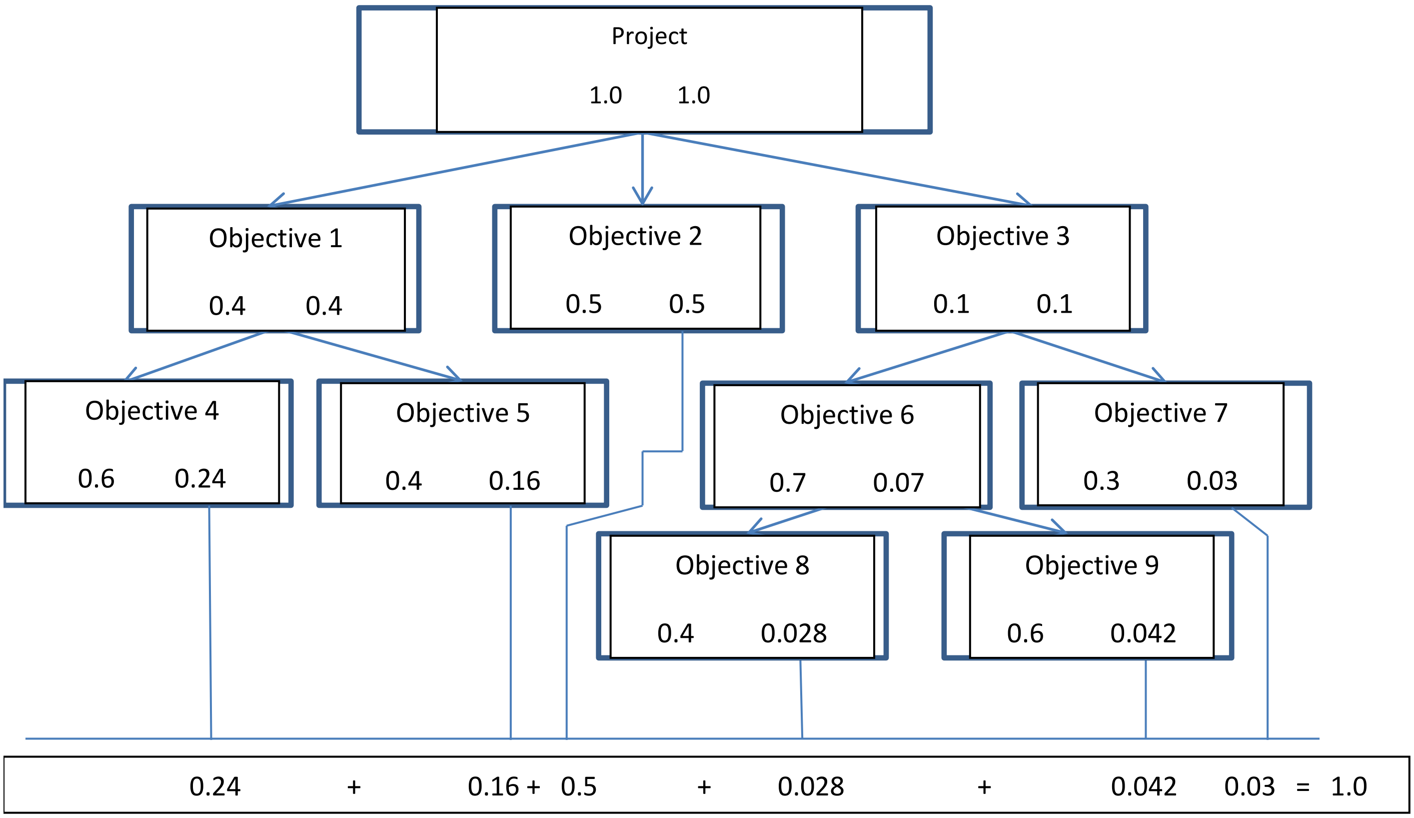


Fig. 2 Template of an Objectives Tree

<u>Establish Functions</u>

This step of the design process is the first formal attempt at the solution to the project. The solution is functional rather than conceptual. A concept is recognized as something that is physical in description. A functional solution ahead of the conceptual solution is extremely beneficial but is often not learnt or practiced by many engineers. The functional solution makes sure that all functions needed to create, assemble/transport/install, operate, maintain, service, and retire/recycle the product are identified. These functions can be categorized broadly as pre-usage, usage, and post-usage sub-functions. The Function Analysis Flowchart (FAF) is the method used to document the functions. The FAF is a flowchart of functions arranged to suit each project. A template of the FAF is shown in Figure 3. Students are asked to first come up with their individual version of the FAF before they finalize a team version. FAF engages the students in creative engineering (Obj1). The realization of a team version of the FAF from individual versions requires that students participate in the dynamics of team effort (Obj3). In coming up with a team version, ability to orally articulate each students' functional ideas are very important (Obj7).

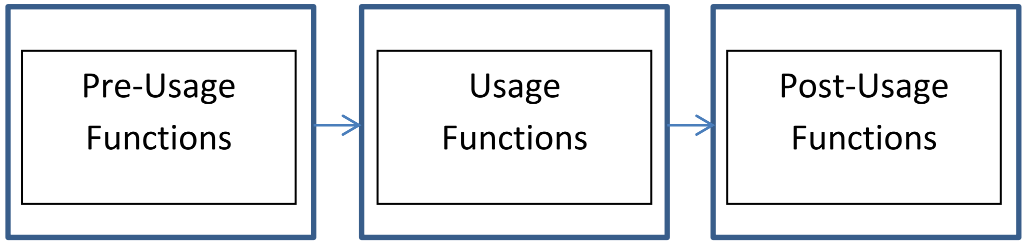


Fig. 3 Template of the Function Analysis Flowchart (FAF)

Determine Specifications

The method adopted to determine engineering specifications is the House of Quality[2] (HOQ). The template for the HOQ is shown in Figure 4. As is well known in the literature, the HOQ enables the translation of customers' requirements to engineering specification and establishes target ranges for each engineering specification that the project design must achieve while taking into account the competition. The House of Quality provides the robustness of enabling quality, cost effectiveness, and competitive design in every project. The generation of the House of Quality addresses Obj5 besides Obj1, Obj3, Obj4, and Obj8.

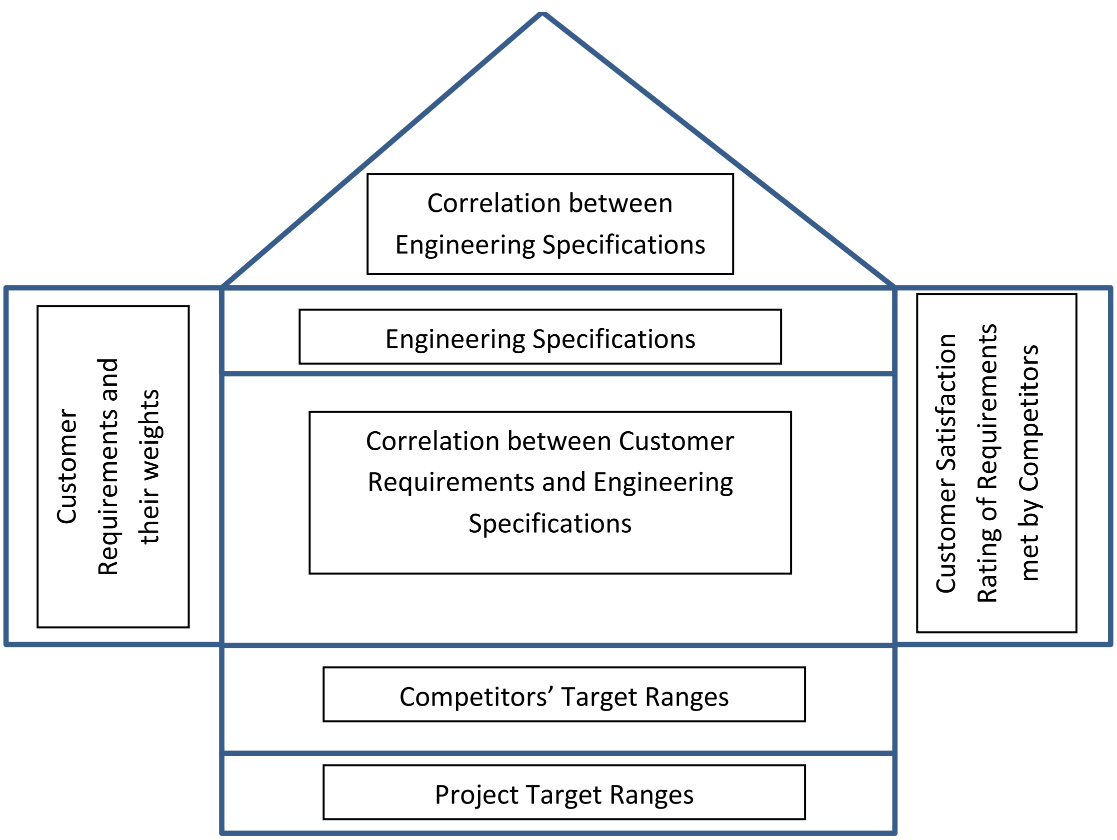


Fig. 4 Template for House of Quality (HOQ)

Generate Concepts

This is the step where students creatively identify concepts for each function in the FAF. Each student documents his or her concepts for each function in its 6-3-5 sheet before passing the sheet on to the next student. It should be noted that the 6-3-5 go-around format enables each student to document his or ideas without any peer pressure. Also, this is the step where students address Obj4 the most of critically considering design alternatives (concepts here). The 6-3-5 sheet is one for each function in the FAF. The numbers 6, 3, and 5 symbolically represent a maximum of 6 members per team, 3 concepts from each student for any function, and 5 minutes to come up with each concept. The 6-3-5 documentation addresses the robustness of having every team generate multiple solutions and reduces the possible variability of one team considering many alternatives and another team just one or very few alternatives.

Evaluate and Select the Final Concept

Once every student has created concepts for each function in the 6-3-5 sheet in a go-around format, the team meets to evaluate the concepts and selects the best concepts for further consideration. The concepts still in the running are documented in the Morphological Chart[2]. The morphological chart is a matrix of alternative concepts for each function in every row. A combination of one concept from each row is a potential project solution because such as combination addresses every functional requirement of the design. Through further evaluation, two to five potential project solutions are chosen as finalists. Every team then uses an Advanced Decision Matrix[2] to more objectively evaluate the finalists and selects the Final Concept for Product Development. Evaluations such as the Morphological Chart and the Advanced Decision Matrix are methods that make the evaluation robust across teams. It should be noted that each team is asked to discuss the finalists and their final choice with the sponsor for their approval of either the team's final choice or one of the other finalists for product development.

Develop the Product

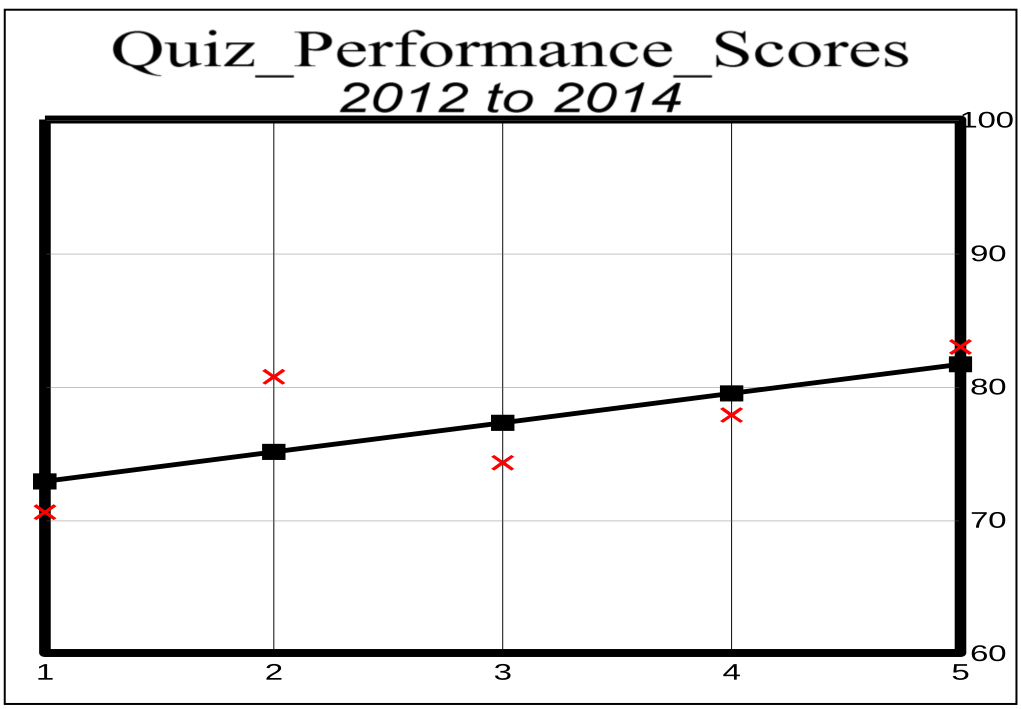
This last step of the design process (often called Product Development) is where Obj2 (apply fundamental principles to design) and Obj5 (consider scientific, technological, social, ethical, economic, and environmental aspects of engineering as warranted) are most addressed. In this step, the concept approved by the sponsor undergoes product development. Product development entails designing the product for performance and robustness (here, the robustness is an engineering robustness achieved through robust design engineering principles[2]), designing for cost, manufacture, assembly, etc. Product development phase also involves solid models, drawings, bill of materials, prototypes, testing, report writing, and presentation (Obj1, Obj2, and Obj5). During this phase, students manage budgets (Obj7) the most to resourcefully complete their projects.

Management Topics

Besides lectures on the steps in the design process which were described above, lectures on management topics are also part of the course. Management topics include time management, engineering ethics, life-long learning, contemporary issues, and personality types. These lectures are followed by students' reflection on some of these topics and feedback to the instructor through surveys (Obj6). The goal of lectures, students' reflection, and feedback is to make the student learning of management issues as robust as possible.

Assessment

The importance of assessment of student learning in this critical course cannot be under-emphasized. Assessment needs to be on several aspects such as understanding of the design process, management and successful executing of design projects, management of time and budgets, effective participation in team dynamics, and leadership. In order to make the assessment robust and thereby minimize the effect of variables clouding the accuracy of assessment, several tools are used. For example, when it comes to leadership, each student gets to be the Project Manager for a few weeks. Individual participation both as Project Manager and Team Member are peer evaluated. As another example, survey on topics such as life-long learning and contemporary issues ensures that every student has had the opportunity to reflect on these topics. Assessment of the understanding of the design process is accomplished through online quizzes as well as the project outcomes. Average class scores on the quizzes over the past few semesters as shown in the chart below reveal the steady, good level, and generally improving trend of student understanding of the design process and related topics. As for the assessment of how well the projects are done, several tools are used such as feedback from sponsors about the project, interim report, final report, and audience evaluation of interim and final presentations. The mechanical engineering program has grown to be the largest on campus at UW-Platteville due to "pull" from industry. This combined with the fact that there are more and more project requests from various companies than needed are the best indicators of successful project outcomes.



Conclusions

This paper has highlighted the importance of a robust approach to the teaching/learning of capstone design project courses in engineering. Many important considerations that are necessary have been identified. They include having clear goals & objectives, course administration plan, suitable design process & methods, suitable projects, appropriate and timely communication enabled by proper documentation, and assessment tools to address a variety of learning outcomes. Assessment outcomes demonstrate that student understanding and implementation of the design process to their projects are steadily improving through robust teaching/learning methodologies adopted in the course. Part of the rigor necessary to accomplish this robust outcome requires that the instructor "lead by example".

References

1 Cross, Nigel, Engineering Design Methods: Strategies for Product Design, John Wiley & Sons, Inc., New Jersey, 2008.
2 Ullman, David G, The Mechanical Design Process, McGraw-Hill, New York, 2009

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