# Quality Assurance of Capstone Senior Design Projects: A Case Study

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## Abstract

A Capstone Senior Design project encompasses all ABET learning outcomes as it summarizes all the essential technical and non-technical skills a higher learning institution prepares its graduates to acquire and apply. A successful and high quality senior design project is proof of the quality of education offered by a higher institute of learning, the quality of its graduates, its faculty, and its facilities. Hence, in order to ensure high quality senior design projects, it is imperative to put in place a quality assurance and monitoring system besides providing essential resources. It is also very important to mentor students and provide them a supportive and conducive environment which encourages creativity and innovation. In this paper, the authors present a case study of how senior design projects in the Electrical Engineering department at Prince Mohammad University (PMU) are systematically administered and monitored to meet the quality standards, educational objectives, and ABET student learning outcomes. Evaluation methods (both direct and indirect) and developed assessment tools used are also presented along with survey results of students' feedback. It is also shown how senior design projects impact the continuous improvement process followed at the program level.


## Introduction

A Capstone Senior Design project undertaken by final year undergraduate students is an essential component of the requirements for successful completion of an undergraduate program in engineering. A senior design project demonstrates, among other things, a student's ability to apply the theoretical knowledge and technical skills in solving a real-world problem, ability to be an independent learner, teamwork and leadership skills, ability to communicate effectively, etc. It demonstrates the competencies and readiness of a senior undergraduate student (after graduation) to either work in the industry or undertake graduate studies and conduct research. It encompasses all ABET learning outcomes as it summarizes all the essential technical and non-technical skills a higher learning institution prepares its graduates to acquire and apply. In short, a successful and high quality senior design project is proof of the quality of education offered by a higher institute of learning, the quality of its graduates, its faculty, and its facilities. Hence, in order to ensure high quality senior design projects, it is imperative to put in place a quality assurance and monitoring system besides providing essential resources. It is also very important to mentor students and provide them a supportive and conducive environment which encourages creativity and innovation.

Based on recent published literature, capstone project quality assurance varies across different programs in terms of mechanisms and methods adopted [1]. Some programs experimented with new management styles such as scrum [2-4] that is based on cyclical feedback process and offers rapid prototyping and more transparent teamwork. Others opted for integrating systems engineering process for product development to improve quality and better student preparation for future careers [5-7]. Some studies focused on the importance of improving group selection,

effective teamwork and motivation for overall project quality [8-11]. Another way to ensure quality projects is to establish partnerships with local industry to identify projects topics and collaborate in monitoring and evaluation [12]. Aligning projects with community service and causes such sustainability [13-18] proved to increase students' motivation, creativity and improve project success.

In addition to adopting effective team selection, better management, motivation and partnerships as discussed in above studies, the issue of bridging the gap between classroom structured methods and capstone open-ended design must be addressed. To prepare students for capstone design most programs integrated design in other lower level courses and used projects as a driver for continuous program improvement [19-21]. The task of finding tools for effective assessment of ABET outcomes remains a big challenges and needs continuous refining [22, 23].

The EE department at PMU follows a project-based learning approach. Most EE courses require students to complete a course project which helps students apply the knowledge and skills gained through the classroom lectures and laboratory exercises. This approach prepares students to work on higher quality senior design projects.

Students in the EE department at PMU are required to successfully complete a senior design project in the final year of their undergraduate studies in order to graduate. Each senior project is executed by a group of up to four students where they apply the knowledge they have acquired to demonstrate their mastery of the discipline. Students can either choose a project from the published list of senior design projects proposed by EE faculty or submit their own project proposals to the course coordinator for an official approval. A faculty advisor is assigned to each design project to supervise and guide the project throughout its completion. The major stages of the senior design projects are: identification of requirements and specifications, system design, prototype implementation, and testing and verification. Students are encouraged to take responsibility for individual tasks and work together in a team according to the project plan and achieve project goals. This paper presents a case study of senior design projects (in the Electrical Engineering department) at PMU systematically administered and monitored to meet the quality standards and ABET student learning outcomes. Evaluation methods (both direct and indirect) and developed assessment tools used are also presented along with survey results of students' feedback.

## Administering Capstone Senior Design Project

The Capstone senior design projects at the EE department at PMU are administered and executed over a period of two semesters comprised of the following two courses which are worth 3 credit hours each:

1. *EEEN 4311:* Design Methodology and Project Management (Senior Design I)
2. *ASSE 4311:* Learning Outcome Assessment III (Senior Design II)

Two different instructors are engaged in the delivery of these two courses. Considering the relatively small size of the EE department (in terms of total student enrolment of around 400), the number of students registered in Senior Design I (EEEN 4311) in a given semester may range from 25 to 35 students. They are divided into groups of 3 to 4 students, forming 6 to 9 teams. This cohort of students then moves on and continues to work on the project towards its completion in Senior Design II (ASSE 4311) in the following semester with another Instructor. The faculty teaching these two courses have a standard workload of 12 to 16 credit hours depending on their academic rank. Table 1 lists the course components for both courses. With a project-based learning approach, most EE courses require students to complete a course project which enable students apply the knowledge and skills gained through the classroom lectures and laboratory exercises. This approach prepares students to work on higher quality senior design projects as adopted by other institutions in their quality assurance processes [19-21].

Table 1: Course components for *EEEN 4311* and *ASSE 4311*.

| | **Lecture** | **Tutorial** | **Laboratory/ Studio** | **Practical** | **Others (Presentations)** | **Total** |
|---|---|---|---|---|---|---|
| **Credit Hours** | 3 | 0 | 0 | 0 | 0 | 3 |
| **Contact Hours/term** | 30 | 0 | 0 | 6 | 9 | 45 |

After each team selects its topic for the senior design project, it is assigned an advisor from the EE faculty who coordinates with the course instructor in mentoring the students and monitoring the project.

EEEN 4311 (Senior Design I) is the first of the series of two courses comprising the Capstone senior design project. In this course, students learn the importance of the design process in engineering, based on product development and design textbook [24] and in line with other institutions' processes [5-7] where engineering design process was followed for quality assurance. The design process is introduced and is taught through its components. Students make use of the design process to define and solve real-world engineering problems. Skills developed and used in the class include describing the design process for both product and system development, writing design specifications for problems, developing a project plan, applying concept generation, applying decision making tools, use of the Quality Function Deployment process, recognizing and discussing ethical issues, and developing an understanding of the role of professional codes and standards and their impact on product safety, quality, and reliability.

The students are required to perform the following activities under the guidance and supervision of the course instructor and their project advisors:

a. Select a project idea and form a team of up to 4 students
b. Identify engineering design principles, professional codes and standards, and engineering ethics that impact project implementation.
c. Prepare a detailed project proposal
d. Prepare a preliminary design
e. Acquire components necessary for project implementation

f. Make a midterm oral presentation
g. Demonstrate work completed according to the project plan
h. Prepare a comprehensive report and make a final presentation

Table 2 lists the detailed course schedule for Senior Design I - *EEEN 4311*.

Table 2: Course schedule for *EEEN 4311*

| Week | Description | Assignment |
|---|---|---|
| 1 | Course overview and introduction, project proposal format.<br>Finalize teams and advisors | (Individual):List of ideas, Teams, Advisors |
| 2 | Project proposal: format, sample<br>L1: Eng Design, Product Development,<br>L2: Product Planning | Teams, Topics and Advisors |
| 3 | L3: Product Architecture: Subsystems and functions<br>L4: Project Management Plan and Team Work.<br>Review of proposal (Project definition & Specs & Background)<br>Background Research Guidelines | A1: Team Project Proposal <u>due</u><br>Literature and research. |
| 4 | L5: Customer Needs and Product Specifications<br>Progress Follow up: | A2: Project Plan <u>due</u> |
| 5 | Midterm Presentation I (Background)<br>Follow up feedback on Presentation I | |
| 6 | L6: Concept Generation, Selection and Testing | A3: Progress Report 1 (Weeks 1-5) |
| 7 | L7: Standards and Codes …<br>L8: Economics,<br>Discussion: Contemporary Issues & Impact of Engineering Solutions | |
| 8 | **Midterm Presentation II**<br>Progress follow up | A5: Progress Report 2 (Weeks 6,7) |
| 9 | Project Report: Format<br>Project Progress Follow up | A6: Progress Report 3 (Weeks 8,9) |
| 10 | Project progress follow up<br>Testing: specifications, plan, analysis … | A7: Progress Report 4 (Weeks 10,11) |
| 11 | L9: Ethics, Reliability, Quality and Safety<br>L10: Intellectual Property and Patents | |
| 12 | Follow up: Meeting with teams | Draft Report Due |
| 13 | Follow up, Report | Draft Report Due |

| | | |
|---|---|---|
| 14-15 | **Final Presentations** | |
| 16 | **F I N A L  E X A M** | |

ASSE 4311 (Senior Design II) is the second and concluding part of the final year senior design project which requires students to complete a design project from concept through to a working prototype. Students carry on from Senior Design I on the execution of their project and perform the following activities for the successful completion of their project, under the guidance and supervision of the course instructor and their project advisors:

a. Prepare project plan for the final stage of the project.
b. Construct hardware and software modules as per system design
c. Refine system design to meet project requirements specifications.
d. Integrate the individual hardware and software modules to produce a working prototype.
e. Make a midterm oral presentation.
f. Prepare a comprehensive project final report.
g. Make a final oral presentation.
h. Demonstrate final project prototype.

Table 3 lists the detailed course schedule for Senior Design II - *ASSE 4311*.

Table 3: Course schedule for *ASSE 4311*

| Week | Description | Assignment |
|---|---|---|
| 1<br>2 | Review Work Completed and Identify Remaining Tasks | Prepare Management Plan for This Term (Weeks 2 - 15) |
| 3 | Meeting #1 | Updated Plans<br>Progress Report #1 (Weeks 1 - 3)<br>Submit Soft Copy and Presentation in Class |
| 4 | Follow up Progress Report #1<br>Meeting #2 | Prepare Updated Powerpoint Slides |
| 5 | Present and Review Plans | Progress Report #2 (Weeks 4 - 5)<br>Submit Soft Copy and Presentation in Class |
| 6 | Presentation 1 (Practice)<br>Follow up Progress Report #2<br>Meeting #3 | All Teams Must Bring Their Project Prototype to PMU Labs for Demo #1/Verify Progress |
| 7 | Presentation 2 (Practice)<br>Hardware Demo #1 | Progress Report #3 (Weeks 6 - 7)<br>Submit Soft Copy and Presentation in Class |
| 8 | Follow up Progress Report #3<br>Meeting #4 | Prepare Midterm Report |
| 9 | **Midterm Presentations, Midterm Report Due** | |
| 10 | Report Review (1): Part 1 | Progress Report #4 (Weeks 8 - 10)<br>Submit Soft Copy and Presentation in Class. |

| | | |
|---|---|---|
| 11 | Report Review (2): Part 2<br>Follow up Progress Report #4<br>Meeting #5<br>Hardware Demo #2 | All Teams Must Bring Their Project Prototype to PMU Labs for Demo #2/Verify Progress |
| 12 | Discuss Testing Vs. Specifications<br>Final Presentations Format | Progress Report #5 (Weeks 11 - 12)<br>Submit Soft Copy and Presentation in Class. |
| 13 | Follow up Progress Report #5<br>Meeting #6<br>Hardware Demo #3 | All Teams Must Bring Their Project Prototype to PMU Labs for Demo #3/Verify Progress |
| 14 | Follow Up on Testing/Demo<br>Follow Up on Report and Final Powerpoint Presentations | Progress Report #6 (Weeks 13 - 14)<br>Submit Soft Copy and Presentation in Class. |
| 15 | **Final Presentations, ALL <u>Deliverables Due</u>** | Deliverables (Soft + Hard Copies): Final Report, Final Powerpoint Presentation, Poster, Brochure, Video, Operation Manual, Prototype |

**Monitoring and Assessment of Senior Design Projects**

Senior design projects are monitored for quality assurance at various stages of its execution starting from its inception with a project idea and proposal through to its final prototype demonstration. Monitoring of senior projects is done through the following:

- Faculty meetings to discuss and approve project ideas
- Midterm oral presentations and prototype demo
- Weekly/bi-weekly meetings with course instructor/advisor
- Periodic progress reports
- Final reports and oral presentation
- Final prototype demonstration

It is worth noting here that ABET Student Outcomes 2 through 7 are evaluated through the above listed assessment instruments in the two senior design courses (as listed later in Table 7).

Each project team is supervised by a faculty member with weekly meetings to monitor and control the timely execution of the project. Project advisors evaluate individual team member progress based on their meeting attendance and timely task completion. Project teams are evaluated through a midterm presentation by a project examination committee. Comments and specific corrective actions are immediately shared with students to make necessary adjustments. At the end of the term, projects are evaluated through final presentation, demonstration, report and poster. Specific forms are used by the project examination committee with specific questions to assess different aspects of design activities.

The EE department has formed a Senior Design Project Committee which follows a clearly defined process for reviewing project ideas, forming project teams, and approving project proposals. Once the proposal is approved, students start their project work. Progress of the project is tracked through weekly meetings and bi-weekly status/progress report. At the end of the project students are required to demonstrate a functional prototype of their design, submit a comprehensive final report, and make an oral presentation to an audience. A set of six forms has been prepared for documenting this process which is listed in Table 4.

Table 4: Project monitoring process and forms used

| # | **Process steps** | **Form used** |
|---|---|---|
| 1 | Faculty/students propose project ideas | **SDP01** – Project Proposal form |
| 2 | Students form teams and select three projects in order of preference | **SDP02** – Student Choices form |
| 3 | List of project teams and project titles are finalized by the Committee | **SDP03** – Project Teams form |
| 4 | Each team completes a project team sign-off form | **SDP04** – Project Team Sign-off form |
| 5 | Teams start working on their projects. Weekly or bi-weekly meetings are held with project supervisors and reports are filed | **SDP05** – Weekly Meeting Report |
| 6 | Students' performance is monitored and documented on a bi-weekly basis | **SDP06** – Student Performance Monitoring form |

The Committee also oversees all aspects of project execution, monitoring, and quality assurance. It also ensures project teams are assigned to faculty advisors keeping in mind their areas of interest and expertise and reduce individual biases. The oversight of the Committee and the strength of the monitoring process has ensured that any conflict of interests that may arise is nipped in the bud and issues are resolved quickly, especially in the case of Senior Design course instructors also serving as project advisors.

**Evolution of The Quality Assurance Process**

The quality assurance process that is currently applied came about through a process of trial and error and continuous process improvement over a period of more than ten years. Table 5 lists some of the triggers that led to changes in the process. This process will continue to evolve and necessary changes would be effected to improve the quality of projects done, enhance student learning, impart valuable technical and soft skills, and meet learning outcomes.

Table 5: Triggers in the evolution of the Quality Assurance Process

| # | **Trigger/Issue** | **Solution** |
|---|---|---|
| 1 | Prior to the year 2014/15, EEEN 4311 and ASSE 4311 used to be offered as two independent courses without any linkage; | linked the two courses to improve the quality and scope of the project and administer it over two consecutive semesters |

| | | |
|---|---|---|
| | students would carry out one project for each course; projects were very simple due to short time | |
| 2 | Slow progress, incomplete projects, IP (in progress) grades, etc. | Decided no more IP, better management and progress monitoring, Design I: 10% grade penalty if expected completion level not reached.<br><br>Midterm presentations were introduced as an assessment method and opened to all faculty and students. Students receive valuable feedback during these presentations. For Senior Design I, the midterm presentations help in further refining the scope of the project, and for Senior Design II, they help in course correction (if necessary), discuss alternative solutions, and help solve problems that hinder timely completion of the project. These midterm presentations are extremely helpful in improving the quality of projects and help in timely completion. |
| 3 | Varying project complexity; some groups have relatively easy projects while others very complex; received student complaints | Senior Design Project Committee was formed in the year 2014/15 to oversee all administrative and qualitative aspects of senior design projects, one of the important tasks being reviewing project proposals. Each proposal is thoroughly reviewed by committee members before it is approved. A new proposal form was developed (see Figure 1) to ensure uniformity in difficulty level and complexity across projects; this form is filled out at the idea inception and proposal stage. |
| 4 | Assessment and evaluation of student outcomes were not systematic and not mapped directly to assessment methods used | Developed rubrics and evaluation forms for assessment methods such as presentations, final report, prototype demonstration, etc. |
| 5 | Student feedback was not obtained formally | Survey forms developed as instruments of indirect assessment to get feedback from students and improve the process |

Some of the important stages of the quality assurance process currently applied and the activities carried out to meet certain goals are listed in Table 6 below:

Table 6: Quality Assurance Process Steps, Activities, and Goals

| Process Step | Process Activities | Goals |
|---|---|---|
| Team selection | Completed during first week by letting students make the initial selection. Project Committee will review and approve and may suggest changes if the number exceeds the limit or … | We tried other ways of team selection and found that involving students results in less issues and better motivation |
| Topic & Advisor Selection | Students are encouraged to contact faculty and discuss their topics to find a match | Again, if students choose their advisor they most likely will be more responsible and motivated |
| Proposal | Students write their project proposal in coordination with course instructor and advisor and submit it for committee approval. | Target to have this finished by week 3 of the semester |
| Committee Approval | Committee meets to discuss project teams and proposals to make sure teams are balanced and topics have the appropriate scope and complexity | Target to have this finished by week 3 so students can start working. |
| Project Plan | Students write their project management plan in coordination with course instructor and advisor | Use project management tools such as Gantt Charts, PERT or CPM |
| Midterm Presentation | First opportunity for students to define their project, discuss their strategy and receive feedback from committee | Used to improve students presentation skills and also to monitor and suggest improvements |
| Progress Monitoring | Continuous through all stages and done by advisors, instructors and Committee with feedback provided to help students make the most appropriate and effective decisions. | Try to catch any problems early and fix them to avoid any delays |
| Progress evaluation | Done at multiple stages and covers all aspects (progress, presentations, demonstration, reports, etc.), involving instructor, advisor and Committee | To ensure fairness and average out any bias. |
| Documentation | Templates are provided for proposal, progress reports, final report and presentations | Documents are flexible and ensure important contents are included for completeness and assessment purposes. |

As shown in tables 5 and 6, team selection and monitoring teamwork is very important for overall project quality which was the focus of other institutions [8-11] and their effort to find ways to improve teamwork effectiveness and motivation. In addition, our project topic selection has been mostly aligned with community service and important causes such as sustainability which helped to increase students' motivation, creativity and improve project success [13-18].

As our quality assurance process continues to evolve, one area that we are working to improve is to involve local industry in our process by establishing partnerships to identify projects topics and collaborate in monitoring and evaluation [12]. Another area where we need to improve our process is in the formal deployment of QFD (which is studied in Senior Design I); industrial collaboration will be a step in this direction.

**Project Sign-off**

Preparing a project proposal is the most important task of the project as it defines the project and its scope in the form of clearly defined requirements specifications. This task is carried out as the first task in Senior Design I course. The project idea may either be proposed by a faculty member or may come from the students themselves. Project ideas are proposed using the project proposal form (SDP01) and submitted to their Senior Design I course instructor, as shown in Figure 1. In some instances, students may select more than one idea proposed by the faculty members as they fill out the Student Choices form (SDP02). All project ideas are discussed by the EE faculty over several meetings to make sure the scope, difficulty level, team composition, etc. of each project meets the following requirements:

a. Each project is related to the broad areas of EE with several subsystems present.
b. The complexity of a project requires two semesters worth of time and effort, and no project is either too difficult or too easy.
c. Projects are comparable in terms of difficulty level.
d. Parts/components can be procured easily.
e. Department facilities (laboratories, equipment, etc.) are sufficient for project implementation and testing and verification.
f. Teams are evenly balanced.

Next, the Project Teams form (SDP03) is filled out after finalizing project teams and one project for each team. Each team is then required to fill out the Project Team Sign-off form. The teams are now given the go-ahead to start working on their projects. They are first required to prepare and submit a detailed project proposal.

FORM: SDP01

| | SENIOR DESIGN PROJECT – PROPOSAL FORM<br>**Department of Electrical Engineering** |
|---|---|

| SEMESTER: | Spring | ACADEMIC YEAR: | 2019-20 |
|---|---|---|---|

| | | |
|---|---|---|
| **PROJECT TITLE** | Automatic Car Side-view and Rear-view Mirrors Adjustment and Drowsy Driver Detection System | |
| **BRIEF DESCRIPTION** | The purpose of this project is to increase driver safety by incorporating the following functions in a car using an infrared camera mounted inside the dashboard and other sensors:<br>• Perform automatic adjustment of side-view and rearview mirrors using the camera and ultrasonic sensors to track the driver's eyes and head position. This will minimize accidents due to blind spots and misalignment of the side-view and rearview mirrors.<br>• Detect driver drowsiness and alert the driver by generating an audio alarm. Many accidents happen due to driver falling asleep while driving. Drowsiness is mostly due to the monotonous activity of driving for long periods of time and also due to physical stress or driving fatigue.<br>➢ Keeping the driver focused, engaged, and mentally active<br>➢ Suggest driver to get some rest, drink coffee or play his favourite song, play favourite news/sports channel, etc. | |
| **PREREQUISITES** | **C/C++, Python, Microcontroller programming and interfacing** | |
| **NO. OF STUDENTS (REQUIRED)** | **4** | |
| **SUPERVISORS** | **Ahmed Abul Hussain, Gazanfar Latif** | |
| **TECHNICAL REQUIREMENTS** | **Project Subsystems:**<br>☒ Microcontroller<br>☐ Digital Logic<br>☐ Electronics<br>☒ Sensors<br>☐ Communications<br>☐ Signal Processing<br>☐ Feedback Control<br>☐ Power<br>☒ Image Processing<br>☐ Mechanical<br>☒ Software<br>☐ Other: _____<br><br>Project must have at least 4 of the above listed subsystems | **Software Requirements:**<br>☒ C/C++<br>☒ Python<br>☐ Matlab/SimuLink<br>☐ LabVIEW<br>☐ MultiSim<br>☐ CAD<br>☐ Other _____<br><br>**Additional Requirements (if any):**<br><br>A high speed processor is required for image processing |

Figure 1: A Sample Senior Design Project Proposal form

## Project Progress Monitoring

Progress of each project team is monitored regularly by the senior project course instructors as well as project advisors. Weekly meetings are held with the advisor and documented in the Weekly Meeting Report while students' performance in each team is monitored, and documented on a bi-weekly basis using the Student Performance Monitoring form.

Each team is also required to make oral presentations – a midterm presentation and a final presentation. Midterm presentations are particularly useful for getting feedback from all members of the EE faculty. These presentations are also used for evaluating the progress made by the students, team work as well as individual performance. Suggestions are given for finding solutions to difficult problems that stall the progress of the project or to find better ways of doing things or to improve the project in general.

## Instructor-led Monitoring and In-class Activities of ASSE 4311 (Senior Design II)

In order to familiarize the students with the course and assessment strategy, the instructor meets with the class in the first week of the semester. The detailed syllabus is introduced and formats of the submissions including but not limited to Midterm and Final Reports, Progress Reports, Management Plan, and Presentations are demonstrated.

In the case of Senior Design II students, the documents submitted by the teams in *EEEN 4311* are collected to follow up with projects' status. Students are asked to prepare the Management Plan in the first two weeks. The plan lists the project activities planned for the semester within a period of 15 weeks. Each activity is assigned to particular members of the group to be completed within a time limit. This way a work plan is developed and tasks are distributed among group members. Each student takes responsibility in team efforts to complete the assigned tasks. Figure 2 shows an example of the Management Plan.

The Management Plan describes and specifies the activities, procedures, and resources required to build the overall system prototype. It includes the group information such as the group members, student IDs, initials, project title, group advisor, semester and academic year, and progress report number. At the same time, it involves two sections titled, "Progress Details" and "Issues," encompassing the progress report along with issues incorporated. Such progress report is submitted biweekly. Students document their biweekly progress by updating the percentages in the activity section and writing a summary about their accomplishment within the two-week period.

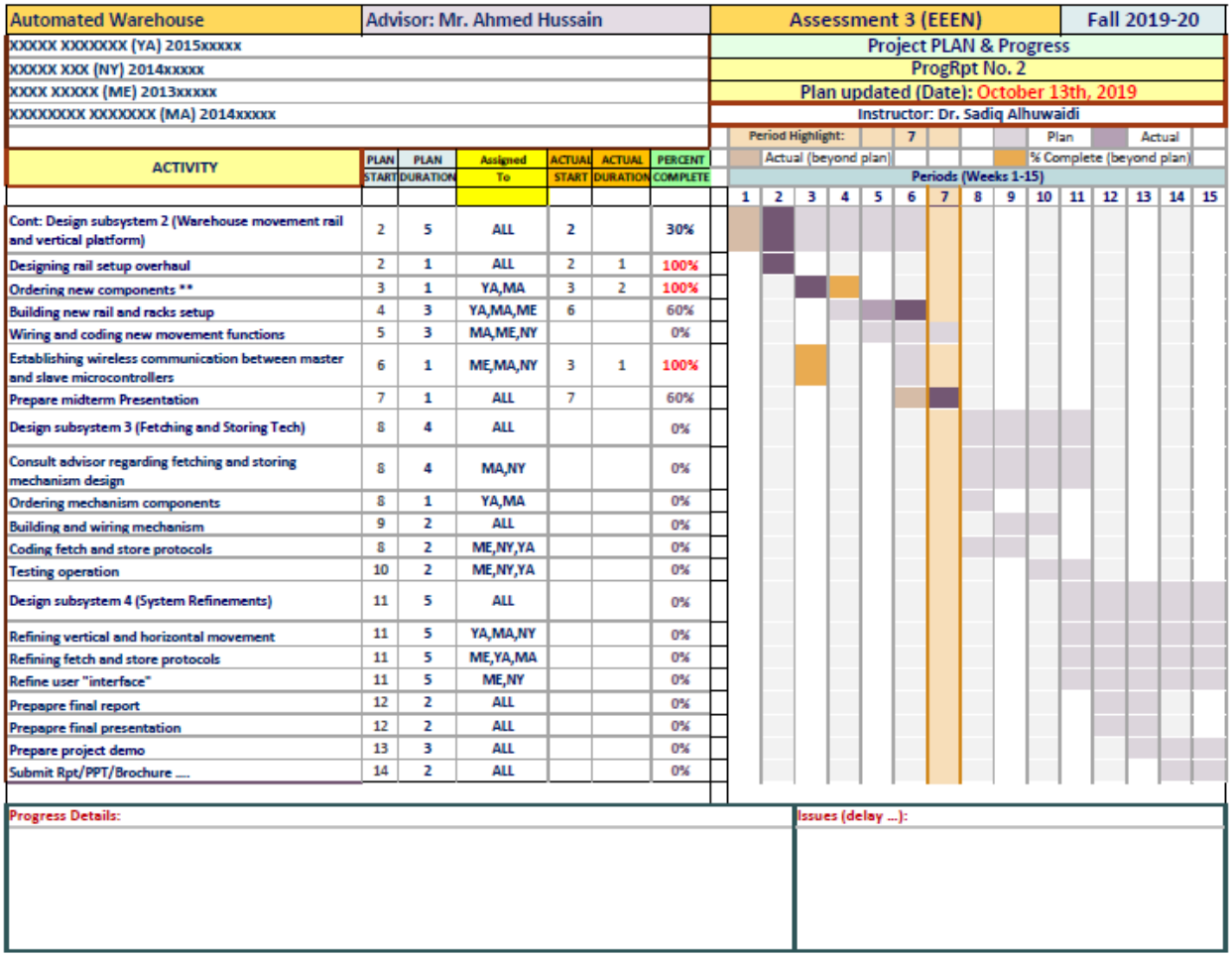



Figure 2: Sample Management Plan in *ASSE 4311*

In addition, individual group meetings are held biweekly for 30-45 min duration to discuss the pre/post testing in the form of submitted progress reports. In the first meeting, the students are also asked to carefully reconsider the portfolio assessment including the stated project specifications submitted in the project proposal such that those specifications can be assessed. This ensures that the students develop a feasible design to comply with required specifications. Also, the final submitted documents in *EEEN 4311* are discussed further based on project research, analysis, design, and specific assignments.

Furthermore, the instructor asks each group to nominate a group member to be the team leader. The team leader coordinates with the instructor regularly to set individual group appointments from suggested timings provided by the instructor and make all submissions on behalf of the group. The team leader is responsible to have the other members on track by reaching out to them to choose appropriate timings for appointments for all members, including them in emails and keep them notified with submissions. This provides leadership mentality, controls guidance, and creates collaborative and inclusive environment.

In addition, the instructor monitors the project progress by arranging three (3) demonstrations of the prototype during the semester in Weeks 7, 11, and 13. The final demonstrations are excluded

from those in-semester demonstrations. The components and systems are verified against the design constraints and required specifications.

Students practice the presentations in class before conducting them in the assigned midterm and final presentations to all faculty. For example, they practice the midterm presentation in weeks 6 and 7 before presenting it in week 9 to the wider audience. The practice presentations are time limited. Comments and corrections are shared to enhance the oral communication skills and improve the communication effectively with a range of audiences. Moreover, students are asked to submit short videos during the midterm and final presentations to explain their progress visually.

The instructor provides the required guidelines for final report submissions. Once submitted, the instructor reviews the reports, provides comments, and asks for corrections. Within a specified time-limit, the groups resubmit the final report as the final draft.

**Project Assessment and Evaluation**

A set of rubrics have been prepared to assess the student outcomes both directly and indirectly. Indirect assessment is done through surveys and student feedback. Table 7 lists the ABET student outcomes (SO) assessed and the assessment methods used.

Table 7: ABET Student Outcomes and Assessment Methods for Senior Design I and II

| Senior Design I | | Senior Design II | |
|---|---|---|---|
| ABET SO | Assessment Methods | ABET SO | Assessment Methods |
| 2 | Midterm & Final Exams | 2 | Report, presentations |
| 3 | Report, presentations, Progress evaluation | 3 | Report, presentations, Progress evaluation |
| 4 | Final Exam, Report | 4 | Report, presentations |
| 5 | Advisor evaluation | 5 | Report, presentations, Progress evaluation |
| 7 | Midterm & Final Exams, Project Report | 7 | Report, presentations |

Each project team is evaluated based on its progress in all aspects including attending the individual group meetings, submitting the progress reports on time, and their progress in the prototype demonstrations.

The assessment of individual students within groups is performed based on their presentation performance and the implementation of tasks assigned to each student. Besides, the advisor of the group grades each student separately based on his/her contributions. When presenting, students are questioned at the end of presentation and answers are provided based on activity role. The faculty ensures that each student responds to questions with confidence and positively accepts comments and suggestions. This demonstrates the ethical and professional responsibility at all times.

The following table lists the ABET SOs (1) - (7) and the KPIs for properly assessing each outcome.

Table 8: ABET Student Outcomes and their KPIs

| | |
|---|---|
| 1: Ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. | |
| 1a | Identify the problem and the pertinent theoretical concepts and methods |
| 1b | Formulate the problem using background knowledge (math, science, & engineering) and related constraints |
| 1c | Solve the problem using the most appropriate method |
| 2: Ability to design and conduct experiments, as well as to analyze and interpret data | |
| 2a | Define requirements specifications (scope) and constraints for the component or system to be designed |
| 2b | Develop a feasible design to comply with requirements specifications |
| 2c | Describe and specify activities/procedures and resources necessary to implement the system |
| 2d | Verify the component/system design against the design constraints and requirements specifications |
| 3: Ability to communicate effectively with a range of audiences | |
| 3a | Demonstrate good writing skills following required guidelines |
| 3b | Demonstrate good oral communication skills |
| 4: Ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and social contexts. | |
| 4a | Demonstrate ethical and professional responsibility at all times. |
| 4b | Make informed judgements considering the impact of engineering solutions in different contexts |
| 5: Ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. | |
| 5a | I can develop a work plan and distribute tasks |
| 5b | I can take responsibility in team efforts to complete the assigned tasks |
| 6: Ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions | |
| 6a | I can identify and describe experiment goals, related theoretical concepts and resources to be used. |
| 6b | I can develop and execute a systematic and structured experiment with organized data. |
| 6c | I can analyze and critically interpret data using appropriate tools. |
| 6d | I can draw meaningful conclusions and produce a high quality technical report. |
| 7: Ability to acquire and apply new knowledge as needed, using appropriate learning strategies | |
| 7a | I can demonstrate the ability to independently acquire new skills and knowledge as required |
| 7b | I can demonstrate the ability to apply acquired knowledge and skills to solve problems |

Each KPI for an SO is assessed on a scale of 1 – 4. KPI scores are calculated with the help of a spreadsheet for each assessment method (or instrument) used to assess an outcome. These scores are then averaged over all the assessment methods used and the percentage of KPI scores for each outcome that is more than 3.0 is also calculated. These scores are entered into a Course Assessment Report (CAR) form at the end of the semester. A course report serves as a valuable tool in evaluating the delivery of a course and in assessing course learning outcomes (CLOs) as well ABET SOs.

For senior design projects, the following criteria are used for judging the level of achievement of the student outcomes, with a score of 3.0 considered as the benchmark:

- Achieved (A): Score ≥ 3.0,
- Marginally Achieved (M): Score: 2.5 to 2.99
- Need Improvement (NI): Score < 2.5
- Color code used for the above three categories:

| | | | | | |
|---|---|---|---|---|---|
| Achieved: Score ≥ 3.0 | | Marginally Achieved: Score: 2.5 to 2.99 | | Not achieved: Score < 2.5 | |

Analysis of student performance based on the calculated KPI scores is performed and documented in the CAR form. For each KPI whose score is below the benchmark (3.0) and/or percentage of achievement less than 75%, an action plan is prepared for improving student performance and documented in the CAR form.

The following tables shows the currently used assessment strategy and grade distribution for evaluation of senior design projects:

Table 9: Senior Design I Assessment and Grade Distribution

| Item | Instructor | Advisor | Exam Committee | Totals |
|---|---|---|---|---|
| Progress (reports, meetings, class ) | 7 | 18 | 0 | 25 |
| Final Report | 20 | 0 | 0 | 20 |
| Final Presentation | 0 | 0 | 15 | 15 |
| Completion | 10 | 0 | 0 | 10 |
| In Class & Midterm Presentations | 5 | 0 | 5 | 10 |
| Midterm Exam | 10 | 0 | 0 | 10 |
| Final Exam | 10 | 0 | 0 | 10 |
| Totals | 62% | 18% | 20% | 100% |

Table 10: Senior Design II Assessment and Grade Distribution

| Item | Instructor | Advisor | Exam Committee | Totals |
|---|---|---|---|---|
| Progress (reports, meetings, class ) | 10 | 30 | 0 | 40 |
| Final Report | 20 | 0 | 0 | 20 |
| Final Presentation | 0 | 0 | 20 | 20 |
| Demonstration | 0 | 0 | 10 | 10 |
| In Class Presentations | 5 | 0 | 0 | 5 |
| Deliverables (poster, brochure ….) | 5 | 0 | 0 | 5 |
| Totals | 40% | 30% | 30% | 100% |

As shown in Tables 9 and 10, a significant percentage of the grade is assigned to project progress monitoring by the instructor as well as the advisor – 25% in Senior Design I and 40% in Senior Design II. The progress is monitored through meetings, progress reports, etc.

The following table shows the list of five senior design projects completed during the period Spring 2018-19 to Fall 2019-20 over two semesters.

Table 11: Senior Design Projects, Spring/Fall 2019

| # | Project Title |
|---|---|
| 1 | RFID-based Automated Warehouse |
| 2 | Smart Sensory Energy Metering |
| 3 | Design and Implementation of Electric Vehicle Using Three Phase Induction Motor |
| 4 | Robotic Restaurant Service System (RSS) |
| 5 | Smart Vacuum Cleaner |

Average scores for assessed ABET student outcomes for the senior projects listed in Table 11 are shown Figure 3. For Senior Design I, scores for all outcomes meet or exceed the benchmark of 3.0 except SO 7. While for Senior Design II, all scores exceed the benchmark. An improvement in performance can be noticed, for this cohort, through the increase in scores for the assessed SOs from Senior Design I to Senior Design II.

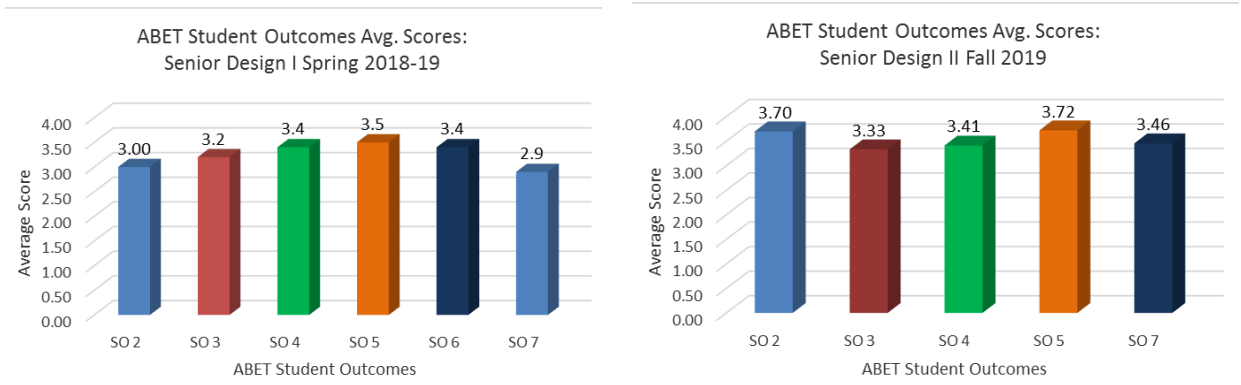



Figure 3: ABET SO Average Score (out of 4) of Senior Design I and II for one cohort (Spring 2018-19, Fall 2019-20) for projects listed in Table 11

The following sections describe how senior design project work is evaluated through the use of various assessment tools for assessing ABET SOs listed in Table 7. The assessment criteria are evaluated on scales of either 1 to 4 or 1 to 10. All these scores are aggregated and utilized in calculating the scores for the ABET SOs as shown in Figure 3.

**Project Work and Final Report Evaluation**

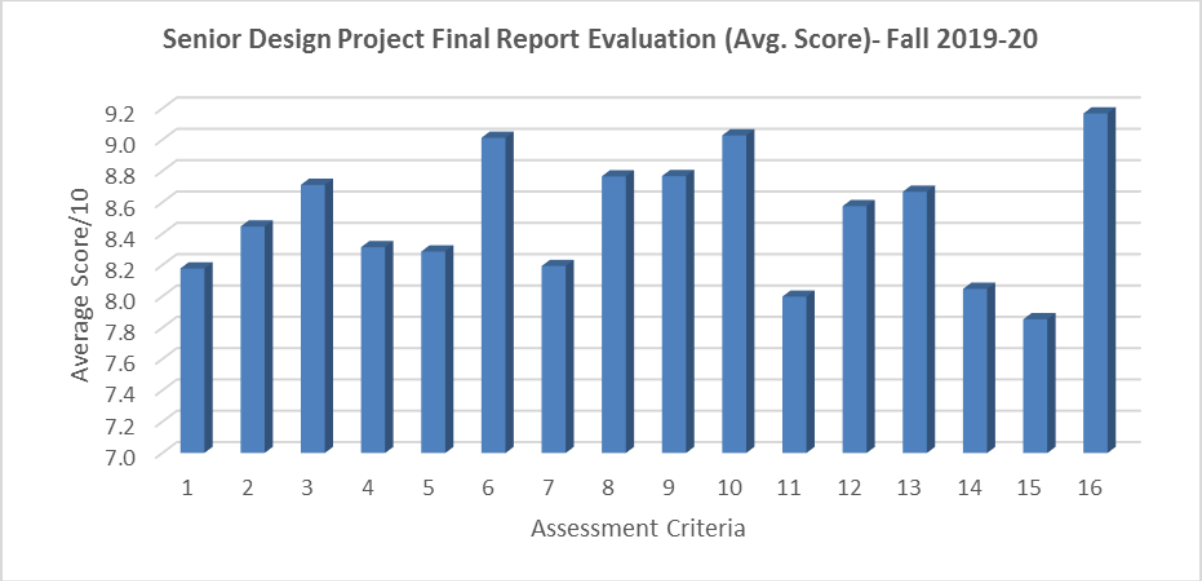
All student projects are evaluated based on the rubrics developed for assessing the functional prototype of the project work and a final report submitted. Evaluation results for each of the projects completed in an earlier academic year are shown Table 10 and the average scores for each assessment criterion are illustrated in Figure 4 (a), while Figure 4 (b) shows the average scores project-wise.

The results of Table 12 show that most scores are above the benchmark of 8.0 out of 10. Scores for Criterion 11 (Final Design) and Criterion 15 (Grammar and overall report writing skills) are slightly below the benchmark indicating room for improvement in following the appropriate design procedure during their project implementation and in preparing a professional technical report. To address these weaknesses, the following actions will be implemented to improve students' design and report writing skills:

- Use junior year course projects to introduce project design procedure at an early stage.
- Use Design I course to train students to formulate their project design specifications (requirements, scope), study alternatives, implement design, and verify using well designed experiments.
- Use Design I course to train students to design appropriate experiments, execute them, interpret results to make appropriate design changes to meet requirements.
- Project advisors will monitor students design activities and suggest adjustments.
- Project advisors will help students to improve their report writing skills by requiring submission of drafts, reviewing them and suggesting corrections.

Table 12: Senior Design Project *Final Report Evaluation* (Average Scores)

| **Projects** / **Assessment Criteria** | RFID-based Automated Warehouse | Smart Sensory Energy Metering | Design and Implementation of Electric Vehicle | Robotic Restaurant Service System (RSS) | Smart Vacuum Cleaner | Avg./10 |
|---|---|---|---|---|---|---|
| 1. Problem Statement and Scope | 8.23 | 7.83 | 8.33 | 8.17 | 8.33 | **8.2** |
| 2. Development of a plan | 8.87 | 8 | 8.83 | 8.33 | 8.2 | **8.4** |
| 3. Project Scheduling and Budgeting | 9.33 | 8.33 | 8.67 | 8.9 | 8.33 | **8.7** |
| 4. Procedure | 8.43 | 7.77 | 8.67 | 8.23 | 8.47 | **8.3** |
| 5. Design Process | 8.3 | 8.23 | 8.33 | 8.17 | 8.4 | **8.3** |
| 6. Use of Computer–Aided Tools | 9.23 | 8.33 | 9 | 9.17 | 9.33 | **9.0** |
| 7. Application of Engineering Principles | 8.2 | 8.17 | 8.5 | 8 | 8.1 | **8.2** |
| 8. Selection and Application of Appropriate Tools, Skills and Techniques in Solving the Problem | 8.83 | 8 | 9 | 9 | 9 | **8.8** |
| 9. Hardware Design | 9.07 | 7.83 | 9.27 | 8.67 | 9 | **8.8** |
| 10. Software Design | 10 | 7.9 | 9.67 | 8.9 | 8.67 | **9.0** |
| 11. Final Design | 7.33 | 7.33 | 8.83 | 8 | 8.5 | **8.0** |
| 12. Verification and testing of the Design | 9.07 | 8 | 9.07 | 7.52 | 9.22 | **8.6** |
| 13. Interpretation of Results | 9 | 8 | 9 | 8.67 | 8.67 | **8.7** |
| 14. Conclusions & Recommendations | 8.17 | 7.5 | 8.57 | 8 | 8 | **8.0** |
| 15. Grammar and Overall Report writing skills | 8 | 7.5 | 8.27 | 7.83 | 7.67 | **7.9** |
| 16. Technical Level of the Project | 9 | 8.67 | 9.83 | 9.67 | 8.67 | **9.2** |
| **Average** | **8.69** | **7.96** | **8.87** | **8.45** | **8.54** | |



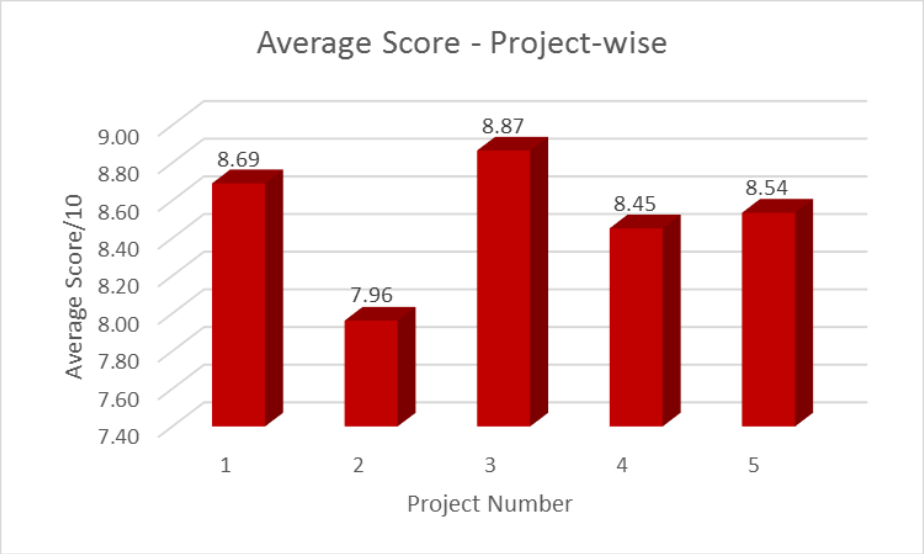




Figure 4: (a) Senior Design Project Final Report Evaluation Average Scores - Fall 2019-20, (b) Project-wise Scores

Figure 5 shows the snapshot of the Table of Contents of Senior Design Project Final Report Template. It shows clearly **one-to-one mapping** of SOs assessed to the assessment instrument (technical section of the report) used. The Final Report is one of several assessment instruments used in assessing SOs in the Senior Design project.

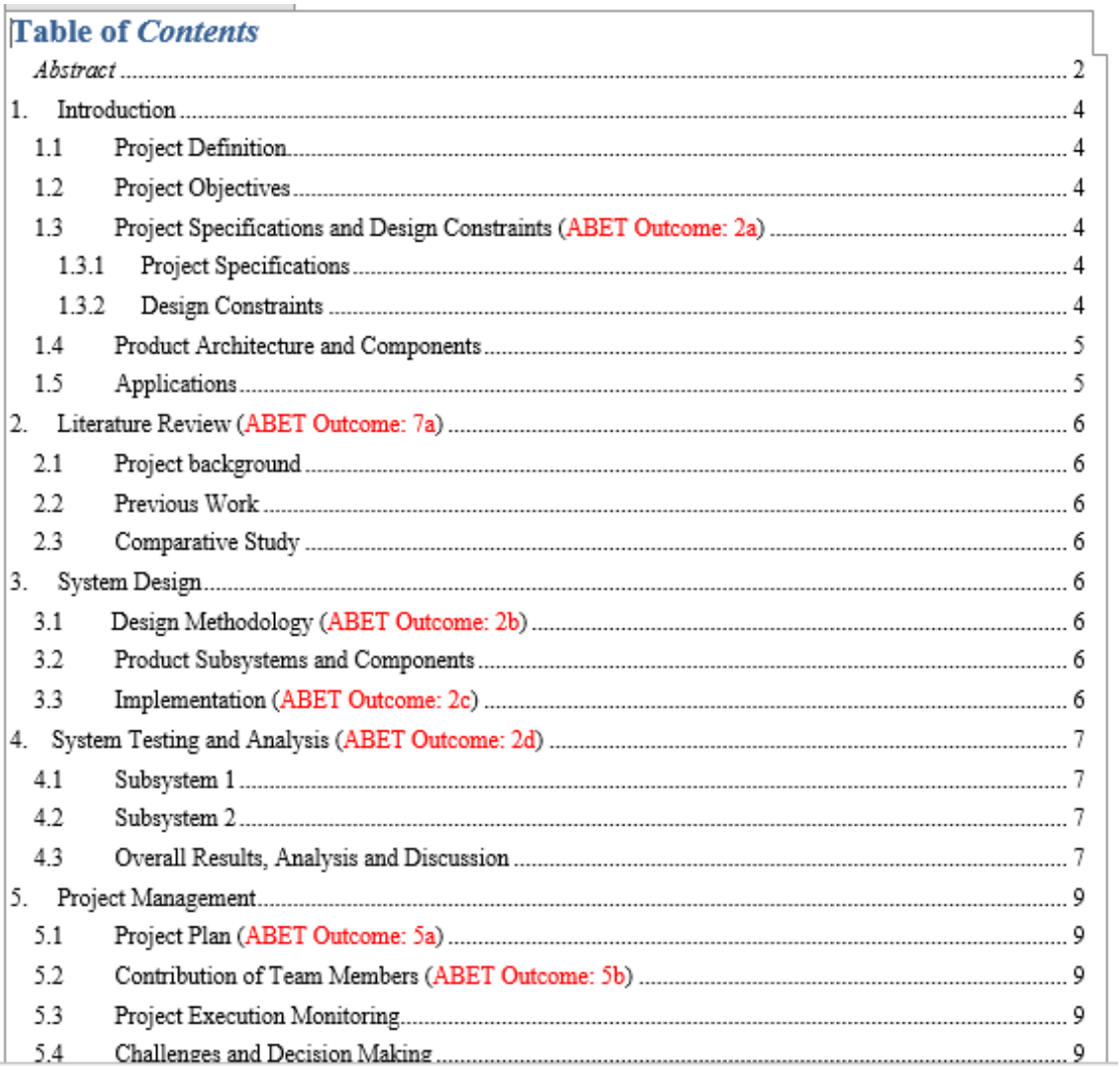


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Figure 5: ABET outcomes 2, 5, and 7 assessed through Senior Design Final Report

Other ABET SOs for senior design projects are assessed through a final presentation and prototype demo.

### Project Final Prototype Demonstration

The final prototype demo evaluation form is shown in Figure 6. It is used to assess ABET SOs 2, 4, and 5.

**Senior Design Project – Final Demo Evaluation**
**Department of Electrical Engineering**

| Project Title: | Date: |
|---|---|

Project team members:

| | | |
|---|---|---|
| | | |

Reviewer: _____

| Score (4 – Excellent; 3 – Good; 2 – Needs Improvement; 1 – Low ) | |
|---|---|
| **Verification and Specifications of System Design (ABET outcomes 2b, 2d)** | |
| 1. Prototype design explained in relationship to problem statement and technical specifications (2b) | ☐4 ☐3 ☐2 ☐1 |
| 2. Demo is shown working without any major glitch. (2d) | ☐4 ☐3 ☐2 ☐1 |
| 3. Testing the Prototype demonstrate the functionality as per the technical specification (2d) | ☐4 ☐3 ☐2 ☐1 |
| **Take Responsibility (ABET outcome 5b)** | |
| 4. The team has demonstrated good team work, coordination, and even distribution of effort. | ☐4 ☐3 ☐2 ☐1 |
| **Professionalism (ABET outcome 4a)** | |
| 5. There is an orderly flow to the demonstration; the demo seems well organized. | ☐4 ☐3 ☐2 ☐1 |
| 6. The team responded professionally to questions and comments. | ☐4 ☐3 ☐2 ☐1 |

Comments:

Figure 6: ABET outcomes 2, 4, and 5 assessed through Senior Design Project Prototype Demo

The results of Table 13 show the Senior Project Demo Evaluation scores for Fall 2019-20. All scores are above the benchmark of 3.0 indicating that faculty were highly satisfied with the demonstration of the project prototypes. These scores are also illustrated in Figure 7. To further improve performance in the areas of team work, project management, and communication skills:

- Project advisors are to ensure that project tasks are divided fairly among all team members and timely progress is monitored and reported for each individual.
- Project advisors are to monitor project execution on a timely manner and suggest solutions to adjust the pace to meet the delivery deadlines.
- Use junior year course projects to improve communication skills.

Table 13: Assessment of *Final Project Demonstration* Spring 2018-19 and Fall 2019-20

| No. | Senior Design Project - DEMO Criteria | Fall 2019-20 Avg/4 |
|---|---|---|
| 1 | Demo is shown working without any major glitch. | **3.81** |
| 2 | There is an orderly flow to the demonstration; the demo seems well organized. | **3.21** |
| 3 | The team effectively demonstrated the relevant design requirements and features of the project. | **3.7** |
| 4 | There is a strong correlation between the oral description of the project and its actual implementation as seen in the demo. | **3.43** |
| 5 | The team has demonstrated good teamwork, coordination, and even distribution of effort. | **3.15** |
| 6 | The team responded effectively to questions and comments. | **3.59** |

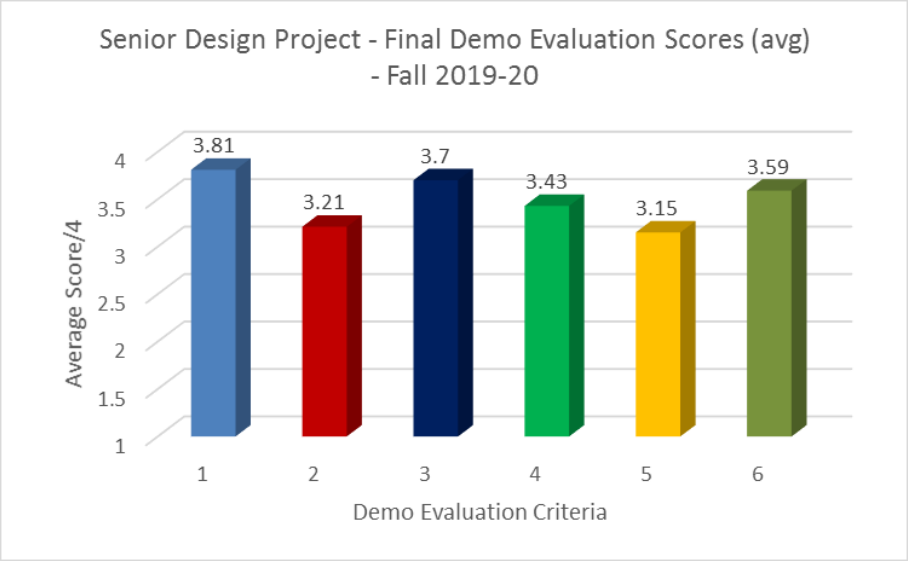


Figure 7: Senior Project Demo Evaluation Results, Fall 2019-20

**Final Presentation**

Students are required to make a final oral presentation at the end of semester which is used for assessing ABET outcome 3 for effective communication skills. A presentation evaluation form which contain 16 criteria as listed in Table 14 is used for evaluating the presentation skills of the students. Each criterion is graded on a scale of 1 – 4 with 4 being Excellent. Criteria numbers 11 to 16 are directly used for assessing the oral communications skills part of ABET SO 3.

Table 14 also shows the assessment results of senior design project presentations obtained from Senior Design Project Presentation Evaluation forms filled out by faculty members, for Spring 2018-19 and Fall 2019-20. These results which are also illustrated in Figure 8 show that all scores are above the benchmark of 3.0 indicating students have satisfactory skills in delivering a good and clear technical presentation. It is worth mentioning here that in the preceding academic

year, most scores were below the benchmark (not shown here). To address the weaknesses, the following actions were implemented to improve skills in producing and delivering effective presentations:

- Used junior year course projects to improve presentation skills by encouraging students to prepare and present short presentations.
- Used Design I course to train students to produce good quality presentation with structured and organized contents from outline to conclusion. In addition, students were trained to interpret their experimental results and discuss their project constraints.
- Used junior course projects and Design I to train students to define their project objectives, perform a literature search and write a problem statement with background information.
- Project advisors helped students to improve their presentations by requiring submission of drafts, reviewing them and suggesting corrections.

As a result of the steps taken for better performance, there was a marked improvement in the scores for Spring 2018-19 and Fall 2019-20 terms.

Table 14: Assessment of *Project Presentations*, Average scores - Spring 2018-19 & Fall 2019-20

| No. | Senior Design Project - Presentation Criteria | Avg/4 |
|---|---|---|
| 1 | Team members appropriately introduced themselves or each other at start | 3.76 |
| 2 | The project title, topic, and objectives were clearly identified | 3.66 |
| 3 | A clear outline of the presentation was provided | 3.58 |
| 4 | Sufficient background information was provided | 3.38 |
| 5 | Work tasks performed or methods used were presented | 3.62 |
| 6 | Preliminary results/findings seemed supported by facts, calculations, experimentation, investigation, or examples | 3.49 |
| 7 | Any major constraints, problems, or challenges were discussed | 3.41 |
| 8 | Conclusions and recommendations were clear and drawn from findings | 3.49 |
| 9 | Presentation slides were clear, concise, and attractive | 3.55 |
| 10 | Presentation slides were supported with pictures, diagrams, tables, or animations | 3.58 |
| 11 | Information was presented in a logical and well-organized manner | 3.54 |
| 12 | The level of information was appropriate for the audience | 3.48 |
| 13 | Transitions and rapport between team members were strong | 3.44 |
| 14 | The team and presentation demonstrated professional behavior and quality | 3.42 |
| 15 | The presentation was audible, well-paced, and well-articulated | 3.60 |
| 16 | Speakers displayed eye contact and positive body language | 3.58 |

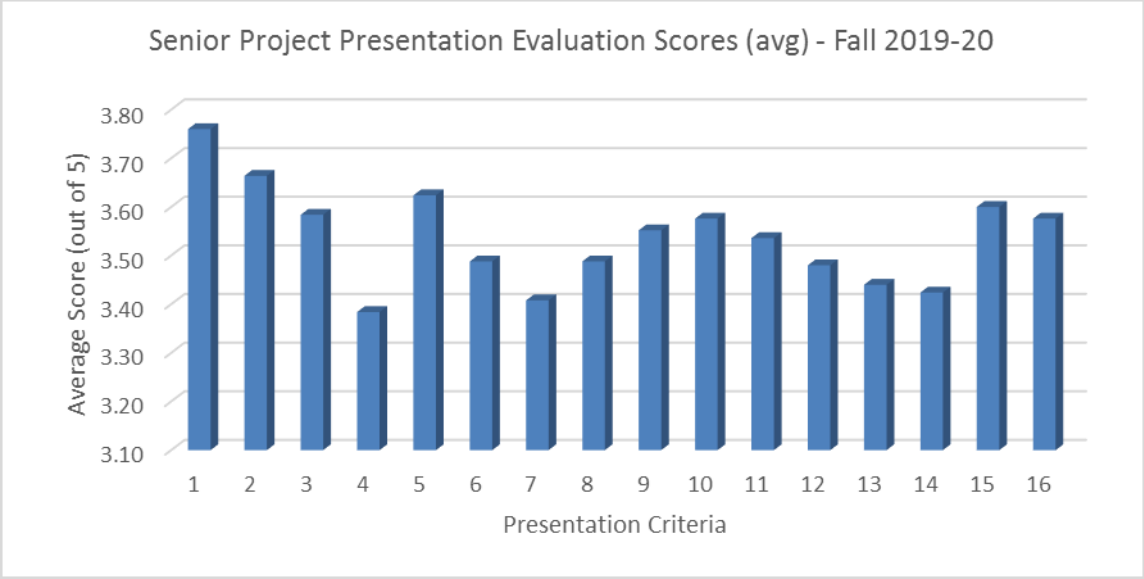


Figure 8: Senior Project Final Presentation Evaluation Average score, Fall 2019-20

**Students Survey on Advising and Support**

Table 15 shows the assessment scores from students' surveys for project supervision conducted at the end of Fall 2019-20. These scores are also illustrated in the chart shown in Figure 9. The results show that most scores are above the benchmark of 4.0 indicating that students are getting the needed support from their advisors, in particular, and the EE department, in general. However, some weaknesses in meeting regularity, reporting of progress, and the desired support from department need to be improved. To address these weaknesses, the following actions will be implemented to improve project support:

- Project advisors will ensure that regular weekly meetings are held and progress reported.
- The Department will work to provide students with appropriate facilities and technical engineering support by hiring more Lab engineers.

As illustrated above, the assessment process has been continuously evaluated and new tools added in an effort to improve effective assessment of ABET outcomes, which is the same challenge shared with other institutions [22, 23].

Table 15: Assessment of *Project Supervision* Fall 2019-20

| No. | Senior Design Project - Student Survey Questions | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | Average |
|---|---|---|---|---|---|---|---|
| Q1 | Your advisor/instructor provided you sufficient guidance in preparing the project proposal and plan. | 4 | 6 | 0 | 0 | 0 | **4.40** |
| Q2 | Your advisor/instructor helped you in defining the scope of the design project. | 4 | 5 | 1 | 0 | 0 | **4.30** |
| Q3 | You received timely technical help from your advisor/instructor and/or other EE faculty. | 3 | 6 | 1 | 0 | 0 | **4.20** |
| Q4 | Your advisor/instructor and/or other EE faculty were available to answer your queries. | 4 | 2 | 4 | 0 | 0 | **4.00** |
| Q7 | You received timely feedback based on your status/progress reports from youradvisor/instructor. | 3 | 5 | 1 | 0 | 0 | **4.22** |
| Q8 | Your advisor/instructor reviewed your project work regularly and provided constructive feedback. | 4 | 4 | 1 | 0 | 0 | **4.33** |
| Q9 | The EE department provided you sufficient resources (such as PCs, software, instruments, HW components, etc.) for your work project. | 5 | 2 | 3 | 0 | 0 | **4.20** |
| Q10 | The EE department provided you project work space and a favorable environment for your work project. | 5 | 4 | 1 | 0 | 0 | **4.40** |
| Q11 | Your advisor/instructor provided guidance in preparing the final report and presentation. | 5 | 4 | 1 | 0 | 0 | **4.40** |
| Q12 | Your advisor/instructor) communicated to you clearly the quality of work expected from a final year project and the assessment strategy. | 3 | 6 | 1 | 0 | 0 | **4.20** |
| Q13 | Your advisor/instructor communicated to you clearly the work (prototype, report, presentation, and poster) to be delivered at the end of the project? | 5 | 2 | 3 | 0 | 0 | **4.20** |

| | Senior Design Project - Student Survey Questions | Weekly | Bi-weekly | Once a Month | Rarely |
|---|---|---|---|---|---|
| Q5 | How often did you meet with your advisor/instructor to discuss project related issues? | 4 | 5 | 1 | |

| | Senior Design Project - Student Survey Questions | Status Report | Progress Report |
|---|---|---|---|
| Q6 | How many status reports and/or progress reports did you submit to your advisor/instructor? Give a number. | 10 | 6 |

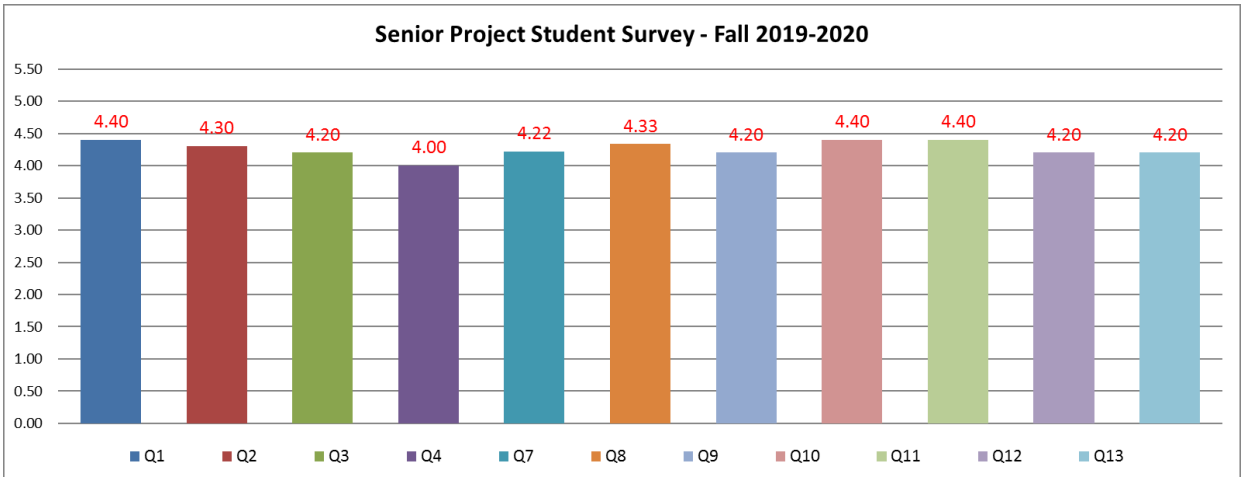


Figure 9: Senior Project Supervision Evaluation Average scores, Fall 2019-20

## Summary and Conclusions

From project initiation to its final prototype, a monitoring process needs to be followed to ensure high quality senior project work and its timely completion. In this paper, the authors presented a case study of how quality assurance of senior design projects is performed in the electrical engineering department at PMU. Assessment methods used and evaluation tools developed for the purpose of monitoring senior design projects were presented. Assessment results were also presented for one cohort of senior design project students who completed their project in Fall 2019-20. All stages of the monitoring and quality assurance process were presented and described in details. Assessment results from various stages of the process were presented and it was also shown how these results are used as inputs for continuous improvement. We have also identified two areas of improvement which will make our process better as it continues to evolve. It is hoped that the case study presented in this paper will contribute to the rich body of knowledge in this field.

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