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An In-Depth Examination of Assessment Methods for Capstone Projects—Measuring Success

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Dr. Muhammad Zilany earned his Ph.D. in Electrical and Computer Engineering from McMaster University, Ontario, Canada, in 2007. He held academic positions at the University of Malaya and the University of Hail before joining the Electrical and Computer Engineering Program at Texas A&M University at Qatar in 2019. His research focuses on signal processing in the auditory system employing a comprehensive approach that integrates computational modeling, physiological recordings, and psychophysical studies. Dr. Zilany developed a computational model of the responses in the auditory nerve for testing our understanding of the underlying mechanical and physiological processes in the auditory periphery, which has been utilized extensively by the prominent auditory neuroscience labs in the field. Dr. Zilany is currently the chair of the ABET and Curriculum committee in the Electrical & Computer program. His commitment to nurturing the next generation of engineers and researchers underscores his role as a mentor and educator. Dr. Zilany is currently a Chartered Engineer with the Institution of Engineering and Technology (IET) in the UK, and he is also a member of the Association for Research in Otolaryngology (ARO) and the American Society for Engineering Education (ASEE).

Muna Sheet, Lusail University

Ms. Muna Sheet has dedicated over two decades to academia, accumulating diverse experiences across five distinguished universities: Texas A&M University at Qatar (TAMUQ), Conestoga College in Canada, University of Toronto (UofT) in Canada, Community College of Qatar (CCQ), and Lusail University (LU) in Doha, Qatar. She earned her Master of Science degree (MSc) in computer engineering and information technology from the University of Technology, Iraq, in 2007, followed by a Certificate in Management of Enterprise Data Analytics from the University of Toronto, Canada, in July 2017. Currently, Muna holds the position of Lecturer at Lusail University, Qatar. Prior to this, she served as a part-time Professor at Conestoga College, Canada, and as a Solution Engineer at CONSULTEK Corporation, Canada. Muna was also a Program Coordinator and a Research Associate at Texas A&M University, Qatar, for more than five years. Throughout her extensive career, Muna has garnered substantial expertise in instructing a wide array of courses, spanning both theoretical and practical subjects. Her teaching portfolio includes Digital Design, Big Data and Data Analysis, Mathematics, Electrical Circuits Theory, Electronics, and Control Theory. Muna's commitment to academia extends beyond the classroom. She actively engages in various committees, contributing her insights and expertise to enhance educational processes. Furthermore, Muna seamlessly integrates her academic prowess with her industry and research experience. She has served as a dedicated researcher at institutions such as TAMUQ and UofT, further enriching her multifaceted background. She is a member of the IEEE.

An In-Depth Examination of Assessment Methods for Capstone Projects: Measuring Success

Abstract:

In academia, data collection plays a fundamental role. It serves multiple purposes, from assessing student learning outcomes to evaluating the effectiveness of instructional methods and developing more efficient methodologies to improve the educational process. This paper explores the distinctive characteristics, purposes, and challenges inherent in data collection and organization from capstone projects, emphasizing the contrasting nature of the data collection approach for regular courses.

Regular courses are from a student's academic journey, having structured curricula and standard assessment methods. Data collected from regular courses typically focus on tracking student performance and evaluating the effectiveness of instructional strategies. The assessment data consists of quantitative measurements. It includes tools like exam scores, assignment marks, lab completion rates, attendance records, and course feedback evaluations. Frequently, data are centered on tracking students' advancement and pinpointing areas where instructional methods, curriculum design, and classroom management can be enhanced. Instructors and educational professionals employ this information to fine-tune their teaching strategies and aid students facing challenges.

On the other hand, capstone projects reflect a conclusion of students' academic experience and emphasize the practical knowledge and skills they acquired for their future professional development. In addition, capstone projects require engaging students in the constraints of the real world to understand what it takes to achieve social value for the proposed solution and, at the same time, attain the promised performance and innovation aspects. The data derived from capstone projects typically possess a qualitative character, demanding thorough analysis. It encompasses subjective evaluations, problem-solving aptitudes, project management abilities, communication capabilities, and teamwork skills.

The data collection process for this study is conducted at the Electrical and Computer Engineering Program of a US public engineering institution. The satellite campus in Qatar adds an international dimension to the capstone projects.

This paper confronts a few challenges arising from the differing data characteristics derived from capstone projects. Data from regular courses can be readily quantified and lend themselves to more straightforward statistical analysis. However, they may not capture the full intricacies and depth of a student's development and progress. In contrast, capstone project data provides rich qualitative, multidisciplinary, and context-driven information. However, they are more challenging to quantify and assess, requiring a detailed rubric that aligns with the capstone projects' objectives.

Introduction:

The mission of the Electrical and Computer Engineering (ECEN) Program is to equip students with a robust foundation in engineering fundamentals, instill the highest standards of professional and ethical behavior, and prepare them to meet the complex technical challenges of society. The program's educational objectives (PEO) [1] are directly related to the student outcomes (SO), which describe skills, knowledge, and behavior that our students acquire as they progress through the program. The program has adopted the student outcomes outlined in ABET Criterion 3 [2] and has structured the assessment of student learning accordingly.

Student outcomes are evaluated based on the results of various tools from regular courses and capstone projects. Tools from regular courses are internally conducted and evaluated by faculty members and students, whereas capstone project tools involve external examiners in addition to faculty members and students. The approach is to identify, collect, and prepare data to evaluate student outcomes' achievement effectively. Some universities in the U.S., such as Villanova University [3] and Temple University [4], adopt a comparable approach. Other universities are observed for employing similar approaches that concentrate on one or two tools [5-7].

This paper describes the assessment process for student outcomes and the tools used to assess course learning outcomes and student outcomes utilized from capstone project courses in the Electrical and Computer Engineering program at Texas A&M-Qatar. The following section describes the relation between PEOs and SOs. Next, the method and framework for evaluating capstone course learning outcomes are introduced as indicators for the attainment of student outcomes. Finally, the SOs assessment, evaluation, and improvement process are illustrated.

Program Educational Objectives and Student Outcomes Relation:

The goal for the ECEN program is that the graduates attain the following PEOs within a few years of graduation:

1. Be competitive as electrical engineers in a diverse range of careers while maintaining high ethical standards
2. Provide service to and assume leadership in their professional disciplines, organizations, and communities around the world
3. Seek and apply advanced knowledge through continuous learning, such as pursuing graduate degrees/courses and professional development in their discipline or other fields
4. Continue developing effective teamwork and communication skills

These outcomes are adopted according to the student outcome of ABET Criteria 3 [2] and presented below:

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
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.
3. An ability to communicate effectively with a range of audiences.

4. An 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 societal contexts.
5. An 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.
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Table 1 illustrates the relationship between the program's educational objectives and student outcomes. As presented next, each student outcome is mapped to multiple education objectives.

Table 1. Relation between PEOs and SOs.

	PEO 1	PEO 2	PEO 3	PEO 4
SO 1	x		x	
SO 2	x	x	x	
SO 3	x	x	x	x
SO 4	x	x	x	
SO 5	x	x	x	x
SO 6	x		x	
SO 7		x	x	

The PEO 1, which concerns the foundation aspects and proficiency essential for successful careers in Electrical Engineering, aligns with SOs 1, 2, 3, 5, and 6. These outcomes are related to graduates' ability to apply knowledge of basic mathematics and science, design and conduct experiments, as well as to analyze and interpret data and design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. PEO 1 also considers graduates' ability to function on multidisciplinary teams, identify, formulate, and solve engineering problems, communicate effectively, and use the techniques, skills, and modern engineering tools necessary for engineering practice.

Concerning PEO 2, which is related to leadership and management skills, it aligns with SOs 2-5 and 7, which are based on graduates' ability to function on multidisciplinary teams, understanding of professional and ethical responsibility, ability to communicate effectively, having broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context, and recognition of the need for and an ability to engage in life-long learning, as well as knowledge of contemporary issues.

Regarding PEO 3, focused on pursuing continuous advancement in knowledge, it is linked with all SOs because it is imperative to succeed after graduation that students should possess strong mathematical skills, be able to make good judgments related to engineering solutions, have effective communication skills, understand ethical issues, function effectively in teams, be able to design and conduct experiments and interpret results, as well as understand the importance of continuously seeking new knowledge for career advancement.

Similarly, PEO 4, which is related to enhancing communication skills continuously, is aligned to SOs 3 and 5, which are based on possessing good communication skills and working effectively in a team setting.

Framework for Capstone Courses:

The senior design project, also known as the capstone project, is a critical component of the program curriculum. It is conducted in the senior year and spans over a sequence of two courses, namely ECEN403 Electrical Design Laboratory I and ECEN404 Electrical Design Laboratory II, and is offered in two consecutive semesters. During the project, students apply the knowledge and skills acquired throughout their study to address and solve real-world problems. The course introduces senior students to the design process and project engineering as practiced in the industry, as shown in Figure 1 [8]. Student teams apply the design process starting from proposal preparation to assembling a prototype, while incorporating appropriate engineering standards and multiple realistic technical and non-technical constraints. Such constraints may be engineering-related constraints such as safety, reliability, and efficiency, or economic, environmental, or social constraints for non-technical related issues. Students implement their project based on the updated proposal, test and evaluate the prototype or application, and submit a final report.

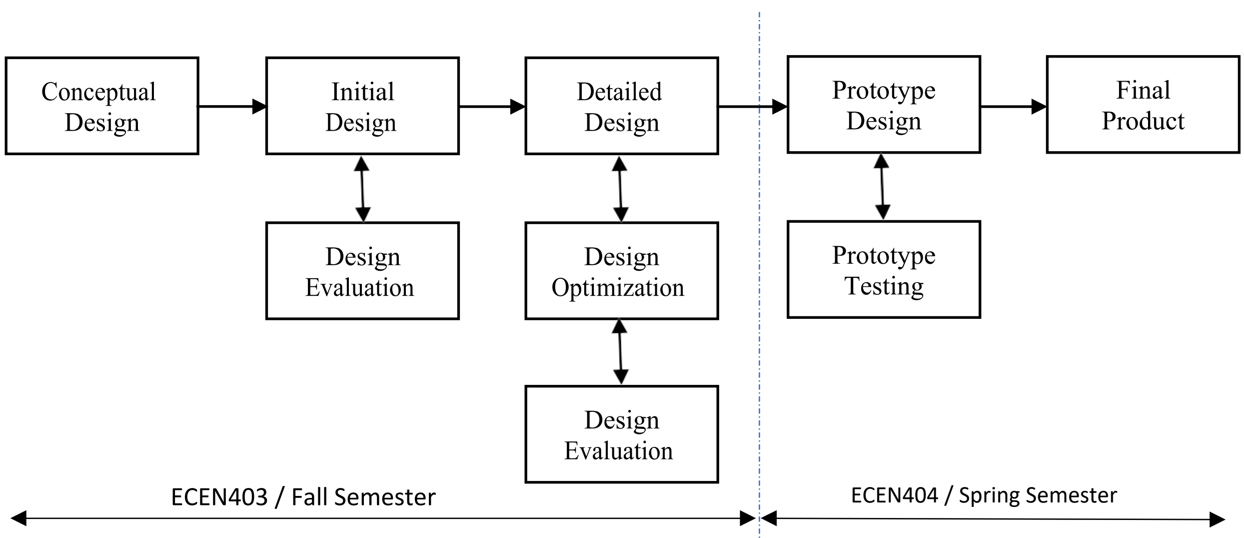


Figure 1: Flow Diagram for Engineering Design Process

Tables 2 and 3 list the course learning outcomes for the capstone courses ECEN403/ECEN404. These tables also illustrate the assessment tool and student outcomes.

Table 2. Relationship of ECEN403 course to Student Outcomes

CLO	Course Learning Outcome	Assessment Tool	Student Outcomes
1	Have experience with writing proposals and doing proper literature reviews.	Project proposal	3
2	Have experience with conducting market and customer needs analysis	Customer needs analysis and Ethnographic study	3
3	Formulate design requirements for potential solutions, including technical and non-technical specifications, while incorporating relevant standards and constraints.	Final report Benchmarking	1, 2
4	Consider the impact of the proposed design on several issues, including ethical, environmental, societal, health, risk, etc.	Ethics seminar summary Ethics seminar quiz	4
5	Have decent experience with product development, product design, and project management.	Functional modeling report	1, 4
6	Ability to present ideas, prepare technical presentations, and effectively communicate with various audiences.	Customer needs analysis Final presentation	3
7	Understand working in a team-based environment	Peer evaluation	5
8	Engage in lifelong learning, including PCB design, embedded systems, etc.	Relevant assignments and quizzes	7

Table 3. Relationship of ECEN404 Course to Student Outcomes:

CLO	Course Learning Outcome	Assessment Tool	Student Outcome
1	Apply knowledge of physics, mathematics, and electrical engineering to identify, formulate, and solve complex engineering problems related to the senior design project.	Final report	1
2	Ability to work in a team-based environment, effectively plan tasks and divide duties to bring the senior capstone project to a successful end.	Peer evaluation	5
3	Ability to recognize engineering ethical issues, specifically those pertaining to the proposed design	Reports and quizzes	4
4	Apply relevant standards and constraints to the proposed design while considering the impact of the design on aspects, including environmental, societal, health, risk, cost, etc.	Final report	2
5	Ability to communicate effectively both orally and in written form with a range of audiences.	Presentations and final report	3
6	Construct, test and troubleshoot (in case of malfunctions) the project prototype, using modern engineering tools.	Progress reports	2
7	Engage in lifelong learning through acquiring knowledge in new technologies, software, etc.	Relevant assignments and quizzes	7

The first capstone course, ECEN403, focuses on training the students based on the academic investigation methodology, including literature survey, writing skills, ethical considerations, engineering ethics, and codes, and transforming an idea into a product, splitting it into a multiphase and thorough approach of research and academic works. Figure 2 illustrates the process map for this course. In this course, students also gain skills to present ideas, prepare technical presentations, and provide proper documentation through progress reports.

Students are encouraged to create their own teams by the end of the first week of the semester and select a project topic. The project topic can be from the shared topics from faculties, industry, communities, or their own topic of interest. Each team consists of three or four members and has a team leader. The team meets with the course instructor for two hours and their capstone supervisor for a minimum of one hour each week.

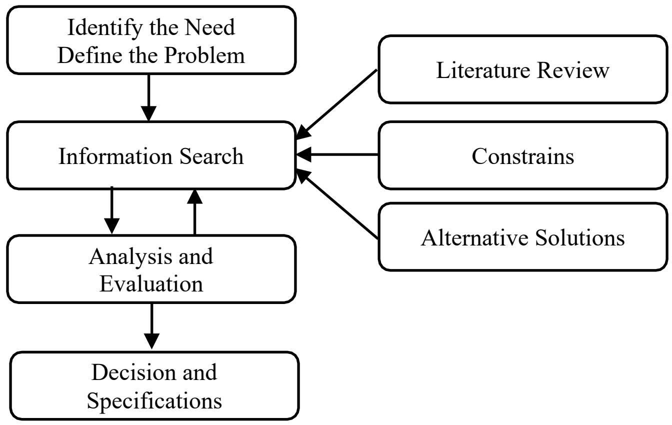


Figure 2: Process Map for the course of ECEN403

In the first meeting, the course instructor shares the course syllabus, which includes a schedule of assignments and deadlines. Table 4 presents the topics covered in this course and the time devoted to each topic. The syllabus also includes the criteria assessment shown in Table 5. Each team is required to get their supervisor's feedback before submitting the assignment to the course instructor. At the end of the semester, the team concludes their progress in a final report, which is then presented to the members of the jury.

Table 4. Topics Covered in the First Capstone Semester

#	Topic	Hours
1	Introduction to Product Design	3
2	Customer needs/Ethnographic study	4
3	Benchmarking	2
4	Functional modeling	2
5	Concept Generation	2
6	Concept Selection	2
7	Student presentation	10
8	Intellectual property	1
9	Engineering Ethics	2
	Total	28

Table 5. Capstone First Semester Assessment Criteria

#	Assessment Criteria	Weight
1	Project Proposal and Team Agreement	5%
2	Customer needs survey, benchmarking, and functional modeling	10%
3	Project Website design and weekly update	3%
4	Project Study Video	5%
5	Presentations	10%
6	Engineering Ethics	2%
7	Peer Evaluation	5%
8	Hands-on Skills Lab	10%
9	Mentor Evaluation	30%
10	Final Progress Report/Detailed Project Plan	20%

In the second capstone semester, the students continue in the real designing phase of their prototype. During this period, they engage in more frequent meetings and technical presentations and work in hand in the lab. Students also learn more about engineering ethics and lifelong learning topics. Each team submits a final report to their project supervisor and capstone course instructor. Table 6 presents the hours distribution in the second semester. It is noteworthy that some of these projects involve collaboration with industry. On Demo Day, the team has to demonstrate a prototype and defend the design in front of a jury from outside the program who will evaluate the final projects. A complete list of capstone projects in the program can be viewed on our website: https://www.qatar.tamu.edu/academics/ecen/academics/senior-design-projects

Table 6. Topics Covered in the Second Capstone Semester

#	Topic	Hours
1	Discussion Meetings	12
2	Technical Presentations	10
3	Seminars	2
4	Engineering Ethics	2
5	Demo Day	4
	Total	30

Table 7. Capstone Second Semester Assessment Criteria

#	Assessment Criteria	Weight
1	Presentations 1, 2 and 3	10%
2	Discussion Meeting	2%
3	Project Website up to Date	3%
4	Peer Evaluation	3%
5	Invited Seminar and lifelong Assignment	6%
6	Engineering Ethics	2%
7	Progress Report	4%
8	Final Report	10%
9	Mentor Evaluation	30%
10	Demo Day (Presentation and Working System Setup)	30%

Evaluation Process for Capstone Project:

Evaluating student outcomes in capstone project courses is a challenging process due to the diverse nature of different projects and multiple examiners with varying areas of expertise. Therefore, rubrics for capstone project courses should be aligned with the course learning outcomes and student outcomes, flexibile to evaluate projects with diverse natures, and suitable for examiners from different area of expertise [R7].

The fulfillment of student outcomes is determined through a particular evaluation process led by the Program Assessment and Improvement Committee (PAIC) in collaboration with the program stakeholders and the industrial advisory board (IAB). This assessment process is based on a comprehensive analysis of results obtained from diverse internal and external assessment tools. Internal tools are performed and conducted internally by faculty members and students, while external tools are conducted by external examiners. The approach is to identify, collect, and prepare data to effectively evaluate the attainment of student outcomes. To achieve this goal, a diverse range of direct and indirect measures utilizing both quantitative and qualitative approaches tailored to the specific outcome under evaluation. A comprehensive overview of the outcome assessment tools employed is provided in Table 8.

Table 8. Student Outcomes Assessment Tools: Type and Frequency of Assessment.

Outcome Assessment Tool	Internal / External	Tool type	Frequency of Assessment	By Whom Conducted	Who Reviews or Acts on Data
Course-based Outcome Assessment Sheet	Internal	Direct	Every semester	Faculty members	PAIC
Course Learning Outcomes Appraisal	Internal	Indirect	Every course	Enrolled students	PAIC
Graduating student survey	Internal	Indirect	Every semester	Graduating students	PAIC
Senior design project survey	External	Indirect	Every year	External examiners	PAIC
Exit interview form	External	Indirect	Every year	External examiners	PAIC

The course-based outcome assessment sheet is conducted by capstone faculty member at the end of each semester. While the graduating student survey is completed by capstone students who ae graduating. For the exit interview and senior design project evaluations are completed by external evaluators conducted at the end of the capstone courses.

The assessment process of the student outcomes is conducted each academic year at the end of the capstone project. In each cycle or round of assessment, the following process is followed:

1. At the end of each semester, students complete a course learning outcomes appraisal for each capstone course they are enrolled in. These appraisals are anonymous and students evaluate each learning outcome based on a scale of one to four.
2. At the end of each semester, capstone instructor conducts the course-based outcome assessment sheet and prepare course reports for the courses they taught. In these reports, each instructor explains how the previous recommendations were implemented and proposes a set

of recommendations for course improvement the next time the course is taught. Students' feedback from the learning outcomes appraisal are also reflected in these reports. The PAIC meets and discusses these reports and develops its own recommendations for improvement.

3. By the end of capstone:
   a. All graduating students complete the graduating student survey.
   b. Members from the Industry Advisory Board (IAB) and other external examiners are invited to attend the oral presentations and demonstrations, called Demo Day, of all senior design projects. They evaluate the projects by completing the senior design form.
   c. External examiners are invited to interview graduating students, and to complete the Exit interview form.
4. At the end of capstone project, the PAIC meets to discuss and analyze all of the above assessment results to identify any shortcomings. The findings of the PAIC are shared and discussed with the IAB members to get their feedback.
5. This evaluation process can result in recommending corrective actions, including:
   a. Modify course learning outcomes or contents.
   b. Modify the tools used to assess the student outcomes.
   c. After several rounds of assessments and evaluation, possibly modify the student outcomes, given the approval of all program constituencies.
6. Finally, the recommendations are submitted to the Program Chair for approving the recommendations starting the following academic year in order to improve the program.

This assessment, evaluation, and improvement process of the student outcomes is schematically illustrated in Figure 3.

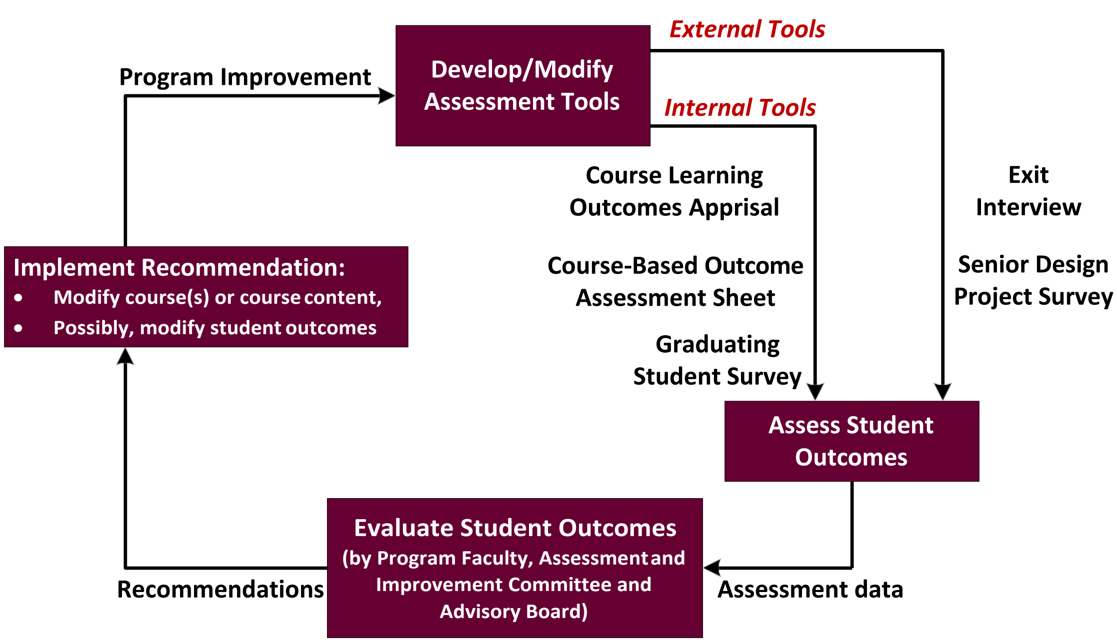


Figure 3. Schematic diagram of the SOs assessment, evaluation, and improvement process.

Assessment Tools for Capstone Project:

The student outcomes are assessed by various methods in capstone project, some of which are performed internally in the program by faculty members and students, and others are performed externally by external evaluators [12].

Internal Assessment Tools:

Internal assessment of the student outcomes is performed mainly through the:

1. Course-Based Outcome Assessment Sheet
2. Course Learning Outcomes Appraisal
3. Graduating Student Survey

The *"Course-Based Outcome Assessment Sheet"*, shown in Figure 4, is used to assess a certain outcome. One or more tools are used to assess a particular outcome as shown in Table 9. The faculty assigns grades for each student in each tool and specifies the minimum passing grade to determine if a student passes that outcome based on his/her performance in all tools used. For satisfactory performance in each outcome, at least 70% of all students should pass each outcome.

Table 9. Tools for Student Outcomes Assessment

Deliverables	Student Outcomes
Final report, 1st semester Final report, 2nd semester	1
Benchmarking Progress reports	2
Project proposal Customer needs analysis and Ethnographic study Presentations Final presentation	3
Functional modeling report Ethics seminar summary and quiz	4
Peer evaluation (1 and 2)	5
Final report, 2nd semester	6
Seminar and crash course Assignment Relevant assignments and quizzes	7

Based on recommendations made in previous years, the passing grade was raised from 70% to 75% as a continuous improvement action, which was triggered by the fact that all objectives had been met with a passing grade of 70% in previous cycles.

Before the end of each semester, students are asked to complete the "Course Learning Outcomes Appraisal" to identify what they have learned and what they will be able to do upon completing the course. Students rate each of the learning outcomes, which are mapped to the program's student outcomes based on the following scale:

- I'm skilled in practice and implementation of the topics/concepts associated with this outcome.
- I understand the topics/concepts associated with this outcome.
- I have limited understanding of the topics/concepts associated with this outcome.

- I have no understanding of this outcome and its related concepts.

Assessment of Outcome:		
Using Course:		
Instructor's Name:		
Semester/Year:		

Tool	Description
1	
2	
3	
4	
5	

No.	Student Name	Tool 1 grade	Tool 2 grade	Tool 3 grade	Tool 4 grade	Tool 5 grade	Avg. %	Pass/Fail
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
	Min. passing grade							
	Max. grade:						**% Pass:**	
	Average:							
	Overall min. passing avg. %:	70						

Figure 4. Course-based Outcome Assessment Sheet Used in Assessing Student Outcomes [12]

Also, graduating students are asked to complete the *"Graduating Student Survey"* to rate the student outcomes based on the following scale:

- I have no mastery of the outcome
- I have a little or marginal mastery of the outcome
- I have a good mastery of the outcome
- I have an outstanding mastery of the outcome

For a satisfactory performance, at least 75% of the responses from all graduating students must be either "I have an outstanding mastery of the outcome" or "I have a good mastery of the outcome." The course-based assessment tool is considered **direct**, whereas the course learning outcomes appraisal and graduating student surveys are considered **indirect**. Nonetheless, all those tools are internal.

External Assessment of Outcomes:

The student outcomes are assessed by various external tools, which are considered **indirect**. These are:

1. Senior design project evaluation, and
2. Exit interview form.

The "Senior Design Project Evaluation" serves as a critical external assessment tool, particularly because the capstone course holds significant weight in assessing program outcomes at the time of graduation. External examiners play a crucial role in evaluating senior design projects, carefully reviewing students' project reports, engaging in discussions with the students, and attending their final presentations and live demonstrations. Following this process, examiners complete an evaluation form including various project-related categories, each of which is aligned with course-related student outcomes. These categories span presentation skills, technical proficiency, impact of design, and team assessment. Detailed criteria for evaluating final presentations and live demonstrations are provided in Table 10, offering a comprehensive rubric for assessment. Examiners assess each student's performance within these categories using a four-point scale: "Exceeds Expectations," "Meets Expectations," "Needs Improvement," and "Needs Significant Improvement.".

The evaluation form results are derived by compiling the responses from all external evaluators across all categories related to each outcome. To achieve satisfactory performance in a particular student outcome, a minimum of 75% of the responses to all questions associated with that outcome must be either "Exceeds Expectations" or "Meets Expectations."

Table 10. Rubric for Senior Design Project Evaluation

#	Presentation Items
1	**Slide Contents:**
1.A	A clear description of the problem statement and the aim of the project
1.B	Detailed Proposed solution
1.C	Technical standards, constraints, and risks.
1.D	Performance criteria (such as economic, environmental, social, political, ethical, health, safety.)
1.E	Advantages of the proposed design over its counterpart designs
1.F	Simulation results, visual prototyping, and analysis for a proposed design
1.G	Functional prototyping, troubleshooting, experimental testing and results
1.H	Conclusions, verification, future recommendations, improvements, and/or optimizations
1.J	Presentation time limit (shouldn't exceed 10 minutes)
2	**Presentation quality and formatting:** theme, outline, organization, fonts, size, slide numbering… etc.
3	**Visual aids:** use of block diagrams, flow charts, figures, and pictures
4	**Ethical standards:** proper referencing for figures and statements, bibliography, and/or acknowledgements
5	**Presentation Skills**: timing management, organization between team members and communication with audience (answers and justification to questions from the audience)

#	Live Demo Items
1.	**Poster:**
1.A	Logical organization of material.
1.B	Clarity of graphics and legends.
1.C	Supporting documentation displayed (References).
2.	**Project: Construction & Testing**
2.A	Prototype demonstrates intended design.
2.B	Prototype has been tested in multiple conditions/trials.
2.C	Prototype demonstrates engineering skill and completeness with recognition of potential impact in engineering, science, economics, environmental, social, political, ethical, health and safety.
3.	Interview:
3.A	Clear, concise, thoughtful responses to questions
3.B	Understanding of basic science relevant to project
3.C	Understanding interpretation and limitations of results and conclusions
3.D	Degree of independence in conducting project
3.E	Quality of ideas for further research
3.F	Contributions to and understanding of project by all members

External examiners conduct the 'Exit Interview' with each graduating senior, utilizing a set of questions outlined in Table 11. These questions are designed to assess the program's effectiveness in preparing students regarding outcomes 2, 3, 4, 5, and 7. Using the exit interview form, examiners evaluate students using a scale that includes 'Exceeds Expectations,' 'Meets Expectations,' 'Needs Improvement,' and 'Needs Significant Improvement.'

Table 11. Evaluation Categories in the Exit Interview

#	Evaluation Category	Sample Questions
(1)	Engineering Design Skills.	- For a given design with constraints, how would you approach the problem? - What performance would you use while taking existing solutions into consideration? Others…
(2)	Oral Communication Skills	- Introduce your strengths and weaknesses. - What do you aspire to be in a few years from now? - What memorable experiences at TAMUQ do you have? Others ….
(3)	High Standards of Ethics.	- How did you use standards of ethics throughout your study period? (Cheating, Copying, etc.) Others ….
(4)	Teamwork skills.	- What makes a team member an effective one? - How to resolve conflicts? Others …
(5)	Contemporary Engineering Applications.	- What advanced technology have you heard about or aware of? - How did technologies help in your courses and projects? Others ….

At least 75% of all responses must be either "Exceeds expectations" or "Meets expectations" for satisfactory performance in each outcome. The outcome assessment process and success metrics are summarized in Table 12 below.

Table 12. Summary of SO Assessment Process.

Assessment Method	Internal/ External	Measurement	Goal
Course-Based Outcome Assessment Sheet	Internal	Using the course-based outcome assessment sheet, each instructor selects 2-5 tools, such as exam questions, projects, quizzes, etc., and uses them to assess that particular outcome for all students. The faculty assigns grades for each student in each tool and specifies the minimum passing grade to determine if a student passes that outcome based on his/her performance in all tools used.	For satisfactory performance in each outcome, at least 75% of all students should pass each outcome in all courses assessed.
Graduating Student Survey	Internal	Each graduating student is asked to identify to what extent they believe the EE curriculum has provided them with the knowledge/abilities to satisfy each of the program outcomes as either "I have no mastery of the outcome," "I have little or marginal mastery of the outcome," "I have good mastery of the outcome," or "I have outstanding mastery of the outcome."	At least 75% of the responses should be either "I have outstanding mastery of the outcome" or "I have good mastery of the outcome."

Senior Design Project Evaluation	External	The capstone evaluation form is completed by external examiners, who go through the students' project reports, discuss the project with the students, and attend the students' final presentations. Then, the examiners fill out an evaluation form covering various project-related categories, which are mapped to the course-related program outcomes. These categories cover various areas, including presentation skills, technical skills, impact of design, and team assessment. In the capstone evaluation form, the examiners evaluate each student's performance in each category based on the following scale: "Exceed expectations," "Meets expectations," "Needs improvement," and "Needs significant improvement." The results from this evaluation form are obtained by compiling the responses from all external evaluators for all categories related to each outcome.	At least 75% of the responses to all questions related to a specific outcome must be either "Exceeds expectations" or "Meets expectations."
Exit Interview Form	External	In the semester of graduation, external examiners interview each graduating senior, asking various questions to assess how much the EE Program prepared each senior with respect to the program outcomes. In this exit interview form, the examiners evaluate the students based on the following scale: "Exceeds expectations," "Meets expectations," "Needs improvement," and "Needs significant improvement."	At least 75% of all responses from all students must be either "Exceeds expectations" or "Meets expectations."

Continuous Improvement of Capstone Project Course by Student Outcomes:

To maintain a continuous improvement process, various inputs are used, namely, the direct and indirect assessment results and feedback from the PAIC, the EE faculty members, and the IAB members. The cycle collect-assess-recommend-implement is done every year. At the end of each year, a self-assessment report is prepared, which contains extensive analysis of the data coming from the various assessment tools. The report also explains how recommendations made in the previous academic year were implemented and what impact they had on the program.

The following are some evidence of implementation and lessons learned from organizing and instructing the course of capstone design project:

1- *Enhance design skills and familiarity with experiments in capstone courses*: In response to this concern, it was suggested to incorporate the design of experiment activities into junior and sophomore level courses as supplementary lab assignments. These activities would entail designing, building, and testing new systems. By including a broader range of experimental design parameters, students gained a deeper understanding of the challenges inherent in proper design. They were also exposed to various implementation alternatives within the design process while ensuring that the results obtained validate the theoretical techniques introduced in the course.

2- *Refine external examiner questionnaire*: It was observed that the results obtained from the external assessment tools lacked sufficient detail, making it challenging to identify deficiencies. After careful analysis of the completed survey forms used for evaluating the presented capstone projects, it was recommended that the questionnaire forms be refined. These refinements aimed to empower evaluators to include informative comments justifying the scores assigned to a project. The primary objective was to identify the weaknesses demonstrated by students and take appropriate corrective actions. Also, considering the limited time available for conducting interviews, the questionnaires were redesigned to focus on more subjective question categories, such as communication skills, ethics, and lifelong learning.

Consequently, questions related to mathematical background were removed, as their evaluation outcomes were deemed to be overly influenced by individual evaluator perspectives.

3- *Close Monitoring of the Team Skills*: After analyzing the results of peer evaluations, it became evident that the teamwork environment fell short of the desired level, requiring corrective measures. A contributing factor to this unsatisfactory result was the timing of the peer evaluation survey, which was conducted towards the end of the course, leaving little opportunity for remedial action. To rectify this, multiple surveys were implemented throughout the semester to promptly identify and address any emerging issues. Consequently, an online peer review evaluation form was developed and distributed to students two to three times during the semester. In addition, students' progress was closely monitored through regular weekly lectures. Teams were tasked with reporting their progress and detailing any challenges encountered, along with their solutions. This approach led to a notable improvement, highlighting the importance of continuous monitoring of team collaboration.

4- *Enhancing the Ethics Component*: Ethics for professional engineers covers a diverse array of topics and situations. However, it was observed that students were introduced to ethics and professionalism components later in their curriculum, with a limited scope in the topics covered. Mainly, the emphasis had been on compliance with the IEEE Code of Ethics. To enhance students' proficiency in identifying ethical issues, constructing well-developed arguments, understanding various ethical systems and Codes of Ethics, and engaging with scholarly sources, it was deemed necessary to broaden the exposure to ethics across multiple courses, starting from the freshman year. As a remedy, the assessment of ethical and professional components was distributed across several courses starting with the freshman year. Assignments within these courses are specifically designed to provide opportunities for students to apply and practice these abilities. The later assessment results demonstrated notable improvement, indicating the effectiveness of this approach in fostering ethical awareness and competence among students.

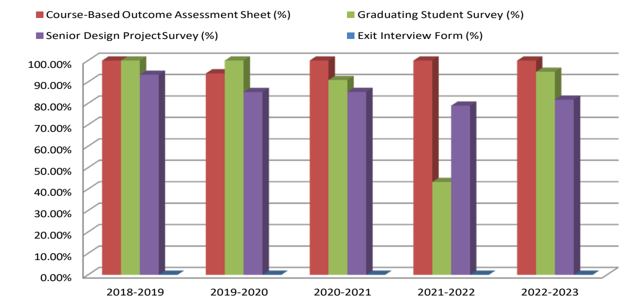
5- *Improvement of the Life-long Learning Tools Approach*: A significant emphasis has been placed on equipping students with the tools for lifelong learning. One effective approach involves conducting short workshops throughout the semester to initiate students into various learning tools. It's crucial that the workshop topics align with students' interests to maintain their motivation and encourage further exploration of the tools even after the workshop concludes. Another approach involves considering the nature of capstone projects and offer the students the needed experience to implement their projects. For instance, students could be presented with a list of possible workshops and let them choose. This not only provides valuable hands-on experience but also encourages self-directed learning and initiative among students.

As mentioned, recommendations for improving the capstone course are derived from the analysis results and feedback provided by external examiners. The comments collected from senior design and exit interview appraisals, combined with the outcome assessment sheet, serve as the basis for assessing each of the student outcomes. Figure 5 depicts the results of student outcomes assessment over the period 2018 to 2023, utilizing the aforementioned evaluation tools.

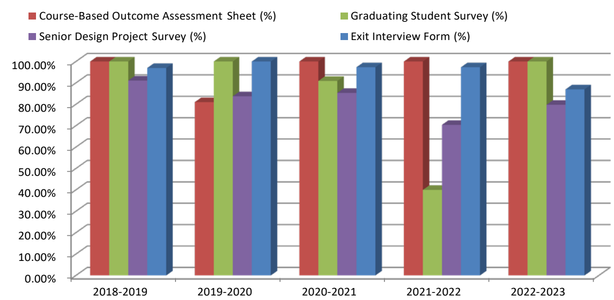
Conclusion:

Rubrics serve as a valuable tool commonly employed for assessing student learning in outcome-based education. Nevertheless, the development and implementation of rubrics in a capstone project course present challenges and contradictions, including 1) ensuring the use of suitable outcome statements for each key performance indicator; 2) the periodic need for refining rubrics based on faculty members' and students' feedback; and 3) maintaining rubric consistency for long-term analysis and tracking of student outcomes.

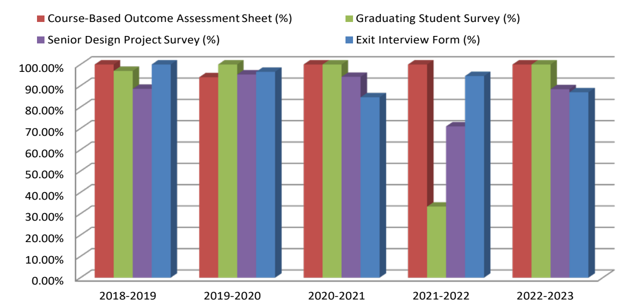
The message of this study is that educators and researchers should adopt assessment methods for both types of data and leverage the benefits each dataset offers. The divergent characteristics of data collected from regular courses and capstone projects complement each other, providing a holistic perspective of a student's academic progress. The integration of these two data sources can contribute to the improvement of educational approaches and better prepare students for the challenges of the contemporary world.



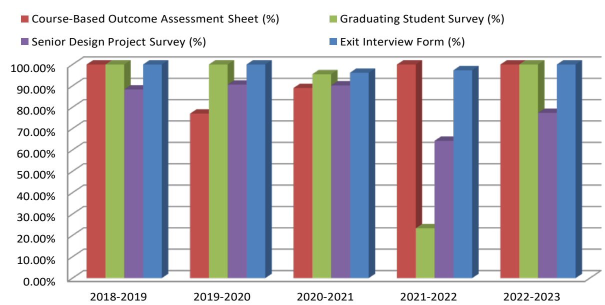
(a) Outcome #1



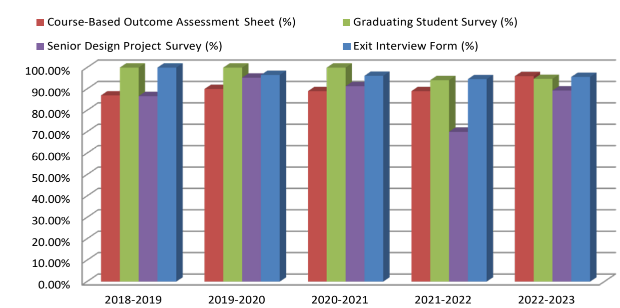
(b) Outcome #2



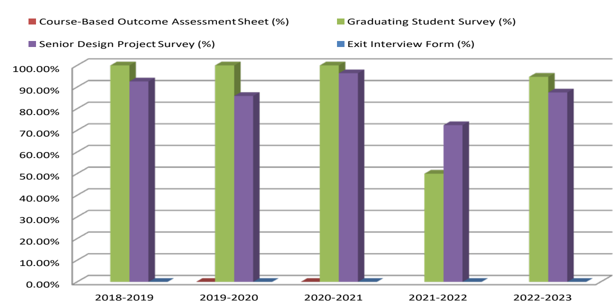
(c) Outcome #3



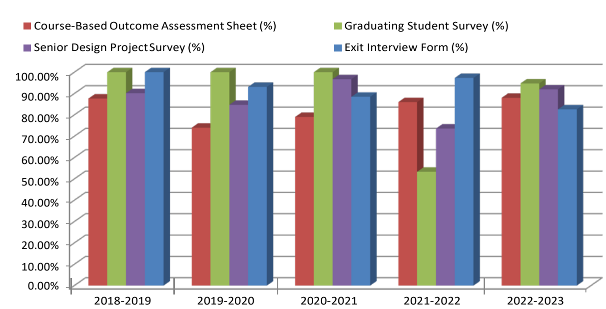
(d) Outcome #4



(e) Outcome #5



(f) Outcome #6



(g) Outcome #7

Figure 5. Summary of Student Outcomes Assessment Results Based on Various Tools for the period 2018 to 2023.

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