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Assessing ABET Student Outcome 5 (Teamwork) in BSME Capstone Design Projects

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Abstract

ABET's Student Outcome 5 concerning teamwork is much more elaborate than the previous Student Outcome d, containing many sub-outcomes. While Student Outcome d focused more on individual student performance on a team and could be suitably assessed with peer evaluation, Student Outcome 5 focuses on the performance of the team as a whole as well as individual performance. As a result, an assessment tool that addresses each of the sub-outcomes has been created and implemented, allowing for greater distinction of strengths and weaknesses within a team. The tool includes both a student survey and instructor-assessed elements. The tool is being used in the capstone design course sequence, and the results from three semesters of implementation are reported and briefly discussed. Compared to the previous method of peer-evaluation alone, the new tool allows each sub-outcome to be measured and evaluated.

Introduction

Mechanical engineering seniors at Lawrence Technological University (LTU) complete a capstone design project: either an SAE collegiate design series (CDS) competition or an industry-sponsored project (ISP). These capstone projects serve as a summative assessment, bringing together machine design, thermo-fluids, manufacturing, and mechatronics topics into a real-world design experience. Relative coverage of these topics depends strongly on the particular design project selected.

Capstone projects are an important component in the engineering curriculum that combine various aspects of students' learning into an integrated team project to address real-world, complex problems. Capstone projects frequently involve multiple elements including design, simulation, fabrication, validation, and cost analysis. This complexity requires system thinking and can easily become interdisciplinary [1, 2]. Due to reporting requirements, interaction with customers and sponsors, and collaboration among different team members, these projects also provide an excellent opportunity for practicing and improving written and oral communication skills [3]. Capstone projects are considered an essential part of engineering training, which help students develop professional skills, interact with industry and community [4, 5], and prepare them for their future careers.

At LTU, competition projects include Baja SAE, Formula SAE, Formula Electric, SAE Aero Design, and SAE Supermileage. The faculty at LTU have found that the SAE CDS is an excellent program for capstone projects. Each team of seniors designs, builds, and competes with their vehicle at one of the SAE CDS events. While some specific aspects of the rules may change for each competition year, the overall objectives and outcomes of these competitions change little from year to year, resulting in the capstone design projects being more structured than ISPs.

Though each team is required to build a new vehicle, previous student team vehicles are available for students to reference which transforms the project from an entirely new design into a process of continual improvement. Timelines are based on SAE deliverables and competition dates which prevents extensions or spillover from semester to semester.

Since 2015, the LTU CDS advisors have worked together to team teach classroom sessions that align with both the developed learning outcomes and CDS project schedules [6]. Learning outcomes consist of both technical and entrepreneurial mindset dimensions. Details on the learning objectives, session-by-session class schedule, and assessment of technical dimensions of the learning objectives were previously described in [7] and details on the learning objectives and activities associated with an entrepreneurial mindset were previously described in [8].

Throughout a capstone project, students must collaborate with diverse individuals in a team environment, which makes it also an important venue for teaching and assessing teamwork. The most recent ABET criteria for engineering programs explains that a team "consists of more than one person working toward a common goal and should include individuals of diverse backgrounds, skills, or perspectives" [9]. The Student Outcome 5 states that students will have "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" [9]. Prior work in the literature has explored ways of forming student teams and assessing teamwork. Common assessment methods include: direct observation by instructors (anecdote), team survey, and peer evaluation [10, 11, 12]. Team surveys usually focus on the whole team function and project success, while peer evaluation gauges the contribution of individual team members. The team survey or peer evaluation is usually completed twice, in the middle of the project and after project completion. The former providing formative assessment while the latter provides summative assessment.

The new ABET Student Outcome 5 is considerably more complex than the old one and it embeds five different sub-outcomes. The previous method of peer evaluation may capture these sub-outcomes but they are conflated in the final scoring. Simply missing the assessment metric does not identify areas for improvement among the sub-outcomes. A new assessment method was needed. This work presents the new LTU Bachelor of Science in Mechanical Engineering (BSME) ABET Student Outcome 5 assessment method in the context of the three-semester capstone design course on the CDS track. Assessment results from 2019-2020 and 2020-2021 teams are presented and discussed.

Three-Semester Capstone Course Sequence

A brief description of the three-semester capstone course sequence follows. Additional details are available in [7, 8]. The course sequence for CDS students consists of three courses: Introduction to Projects, Competition Projects 1, and Competition Projects 2, as shown on the BSME flowchart in Figure 1. Introduction to Projects runs during the Spring semester and introduces students to the CDS projects while using a small-scale "designette" [13, 14] to practice the engineering design process and project management. Students complete a "Declaration of Capstone Team Preference" form to rank their preferences for capstone teams.

The faculty advisors meet to review the student preferences and assign students to teams such that each team has a reasonable chance of success. A majority of the students do receive their first preferences. However, the faculty advisors make case-by-case adjustments including for overall team sizes and the diversity on each team. The Introduction to Projects course also allows for some informal team building, as the competition project has not yet been begun and the team is allowed a more relaxed atmosphere for collegiality. Competition Projects 1 follows in the Fall semester and delivers technical content with studio-like design sessions. Competition Projects 2 completes the sequence in the following Spring semester and includes show-and-tell sessions and design presentations from each team. In April, LTU hosts the annual Blue Devil Motorsports (BDM) Unveiling event, where all vehicles are presented to the University and sponsors prior to competition travel. The credits and offerings for the courses are tabulated in Table 1.

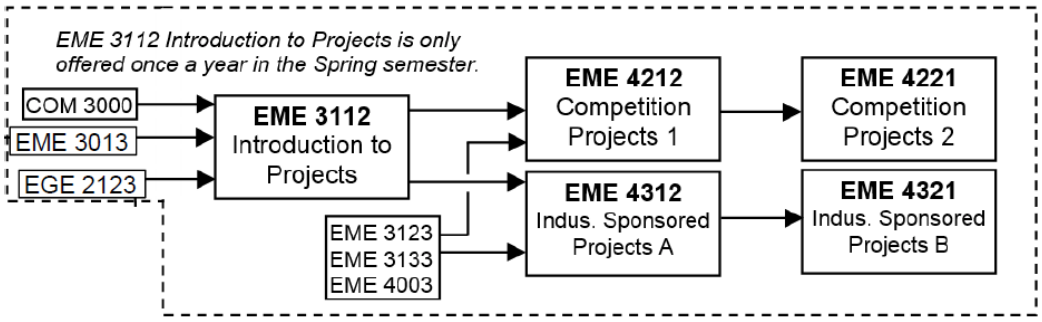

Figure 1. Capstone design portion of BSME flowchart.

Table 1. Course offering schedule.

	Credits	Spring	Fall
Introduction to Projects	2	X	
Competition Projects 1	2		X
Competition Projects 2	1	X	

Each CDS team has a faculty advisor and the three-semester sequence has a course coordinator, as shown in Table 2. Years of CDS experience are also provided for each advisor. Each CDS team is provided with a lab space within the Applied Research Center (ARC) building. The ARC also includes a machine shop, an independent four-wheel chassis dynamometer, a small chassis dyno suitable for CDS vehicles, two water-brake engine dynos (to accommodate different engine sizes), and a wind tunnel. A project engineer oversees the ARC and maintains equipment.

Table 2. SAE competition team advisor and course coordinator.

Team	Advisor	Advisor Years of Experience
Baja SAE	M	8
Formula SAE	J	4
Formula Electric	V	2
SAE Aero Design	G	17
SAE Supermileage	L	6
Course Coordinator	Y	7

Overall ABET Assessment Plan

The LTU BSME program moved from the old ABET Student Outcomes a-k to the new ABET Student Outcomes 1-7 for the 2019-2020 academic year including loop closing in Summer 2020. The LTU BSME capstone design sequences (both CDS and ISP) serve a valuable role in assessing Student Outcomes 2 (design) and 5 (teams). Application of the capstone sequence to other outcomes is possible but not currently used within this program.

Discontinued Teamwork Assessment Method

The now defunct ABET Student Outcome d stated that students will have "an ability to function on multidisciplinary teams." This was assessed twice per semester with a peer evaluation form in which students evaluated all team members, including themselves, on several dimensions as shown in Figure 2. Students were instructed to score with the following criteria: Unacceptable = 0, Poor = 1, Acceptable, Not Great = 2, Good = 3, and Excellent = 4. Examples of unacceptable and excellent team members were provided to students on the back of the peer evaluation page as shown in Figure 3.

	Team Member Names					
Teamwork Elements	Student 1	Student 2	Student 3	Student 4	Student 5	Student 6
1. Communication, Leadership						
2. Commitment						
3. Knowledge of Competition, rules						
4. Attendance, Participation						
5. Preparation for meetings						
6. Contribution to design, reports						
7. Follow through						
8. Skills: technical, fabrication, management						

Figure 2. Sample old peer evaluation form.

ELEMENTS OF TEAMWORK		
	Unacceptable, A Poor Team Member	**An Excellent Team Member**
1. Communication, Leadership	Fails to communicate with team members. Does not respond to emails, etc.	Is open, communicates freely; listens carefully; considers everyone's opinion. Responds to emails, etc.
2. Commitment	Lacks initiative to contribute; gives grudging response to requests; is too busy with own concerns; misses scheduled meetings.	Is always ready to lend a hand; reaches out to help; is readily available; contributes ideas and suggestions; regularly attends meetings.
3. Knowledge of competition, rules	Not aware of the purpose/goals of the competition; has limited knowledge of competition rules.	Has high knowledge of purpose/goals of the competition and rules.
4. Attendance, Participation	Misses team meetings or contributes little. Just along for the ride. Not a valuable team member.	Attends all team meetings, actively contributes. Is a valuable team member during meetings. Participates in BDM/university events.
5. Preparation for meetings	Does not come to team meetings prepared. Can't discuss how their work impacts the project & success.	Comes to meetings prepared & can discuss how their work impacts the project & success.
6. Contribution to design, reports	Brings no or poor engineering designs. Has poorly researched ideas, minimal engineering support.	Brings excellent engineering concepts, well researched designs with supporting analysis & calculations.
7. Follow through	Does not follow through on assignments or complete tasks; neglects responsibility to the team.	Does assigned tasks on time of before due date.
8. Skills: technical, fabrication, management	Has not learned or developed their technical, fabrication, or management skills that are needed for team success.	Has learned or developed many technical, fabrication, or management skills that are needed for team success. Continues to do so.

Figure 3. Example criteria for teamwork evaluation.

The dimension scores were summed for each student-student evaluation. Each student received a score that was the average of evaluations from all team members, including him/herself. The assessment metric was that 70% of students will score 60% or above. This was sufficient to assess the previous Student Outcome d.

Anecdotally, some students took the peer evaluation seriously and put thought into the ratings while others simply marked every team member as excellent in every dimension. No effort was made to separate these cases so the scoring may have been artificially inflated. Further, the peer evaluation scoring was a factor in grades so students had an incentive to cooperate for mutual benefit.

New Teamwork Assessment Method

The new ABET Student Outcome 5 states that students will have "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" [9]. This is a considerably more complex outcome than the old one and embeds five different sub-outcomes:

1. Members provide leadership
2. Team creates a collaborative and inclusive environment
3. Team establishes goals
4. Team plans tasks
5. Team meets objectives

The previous method of peer evaluation may capture these sub-outcomes but they are conflated in the final scoring. Simply missing the assessment metric does not identify areas for improvement among the sub-outcomes. A new assessment method was needed. (Note that peer assessment is still being implemented to inform the advisors of individual student performance.)

The new Student Outcome 5 assessment includes a student teamwork survey and combines that data with team milestones and project completion, both of which are elements of course scoring. Milestones and project completion will be briefly described later in this paper. The new method increases reporting beyond a simple pass or fail and greatly increases the availability of data for continual program improvement.

The survey portion was implemented in Google Forms and provided to the students through the course learning management system. Students were told that "Your names will be recorded ONLY for the purpose of ensuring completion. Your responses will have NO EFFECT on your grade." Because student emails were tracked by Google Forms, it was possible to determine which students did not complete the survey and provide targeted reminders. While responses were not used for grades, participation in the survey was counted as part of the course grade.

The survey asked the students to evaluate teamwork along dimensions linked to each of the sub-outcomes identified above with a 4-point Likert scale from 1 = strongly agree to 4 = strongly disagree. As an example, survey questions regarding "members provide leadership" are shown in Figure 4. All sub-outcomes and associated survey questions are provided in Table 3.

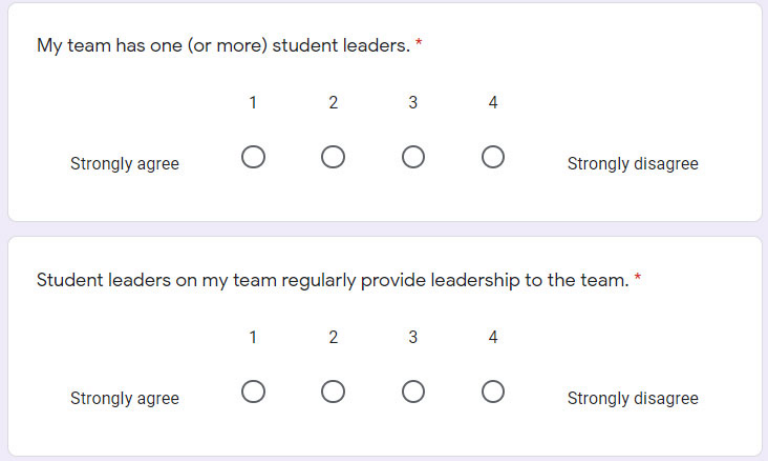

Figure 4. Survey questions related to the sub-outcome "members provide leadership"

Table 3. Sub-outcomes and associated survey questions to be answered on 4-point Likert scale from 1 = strongly agree to 4 = strongly disagree

Members provide leadership	My team has one (or more) student leaders.
	Student leaders on my team regularly provide leadership to the team.
Team creates a collaborative and inclusive environment	My team fosters a collaborative environment.
	My team fosters an inclusive environment.
	My ideas and contributions are valued within my team.
	I feel free to express myself within my team.
	I am included in subsystem-appropriate decision-making within my team.
Team establishes goals	My team established goals (e.g., created a mission statement).
Team plans tasks	My team plans or planned tasks (e.g., created milestones with due dates).
Team meets objectives	My team meets team-created objectives.
	My team meets advisor-provided objectives.

Responses for the teamwork survey were grouped into agreement (scores of 1 or 2) and disagreement (scores of 3 and 4). For each survey question of each sub-outcome, the percentage of students that agreed with the statements was reported.

Quantitative objective data was merged with the teamwork survey to address the sub-outcome "team meets objectives." As described in [7], each team had a project-specific set of milestones designed to help teams progress through the engineering design process. Milestones were evaluated on a team-by-team basis. For some teams (e.g., Baja SAE), each milestone was worth full credit if completed on-time or zero credit if not completed on-time. The percentage of teams that earned at least 75% of milestone credit was reported.

Each team also had a project-specific set of criteria to determine that each student successfully completed their portion of the project [7]. Project completion was evaluated on a student-by-student basis with the syllabus stating that no partial credit would be awarded. The percentage of students that earned 100% of completion credit was reported.

Teamwork Assessment Results

The new teamwork assessment was first implemented in Fall 2019 with data available at the time of publication for Fall 2019, Spring 2020, and Fall 2020. Due to the nature of the three-semester sequence, Fall 2019 and Spring 2020 represent the second and third semesters for one group of students (2019-2020 competition teams) while Fall 2020 is the second semester for another group of students (2020-2021 competition teams). Teamwork data was not collected in the first semester for either group of students.

Fall 2019 and Spring 2020 data is provided first. Team sizes and breakdown by gender are provided in Table 4. Teamwork assessment results are provided in Table 5. Rates for each survey question below 80% are emphasized.

Table 4. Fall 2019 and Spring 2020 team sizes and breakdown by gender

Team	Female	Male	Total
Baja SAE	1	9	10
Formula SAE	4	11	15
Formula Electric	0	11	11
SAE Aero Design	3	7	10
SAE Supermileage	0	10	10

Table 5. Fall 2019 and Spring 2020 teamwork assessment data

		Fall 2019	Spring 2020
Leadership	My team has one (or more) student leaders.	***79%***	85%
	Student leaders on my team regularly provide leadership to the team.	***75%***	80%
Collaborative and Inclusive	My team fosters a collaborative and inclusive environment.	***73%***	***76%***
	My ideas and contributions are valued within my team.	***79%***	88%
	I feel free to express myself within my team.	***77%***	80%
	I am included in subsystem-appropriate decision-making within my team.	***79%***	83%
Plans tasks	My team plans or planned tasks (e.g., created milestones with due dates).	81%	85%
Established Goals	My team established goals (e.g., created a mission statement).	N/A	88%
Meets Objectives	My team meets team-created objectives.	83%	83%
	My team meets advisor-provided objectives.	N/A	85%
	Earns 75% of milestone credit	95%	100%
	Earns 100% of completion credit	***68%***	92%

Fall 2020 data is provided next. Team sizes and breakdown by gender are provided in Table 6. Teamwork assessment results are provided in Table 7. Rates for each survey question below 80% are emphasized.

Table 6. Fall 2020 team sizes and breakdown by gender

Team	Female	Male	Total
Baja SAE	3	9	12
Formula SAE	2	13	15
Formula Electric	2	17	19
SAE Aero Design	2	6	8
SAE Supermileage	1	10	11

Table 7. Fall 2020 teamwork assessment data

		Fall 2020
Leadership	My team has one (or more) student leaders.	85%
	Student leaders on my team regularly provide leadership to the team.	85%
Collaborative and Inclusive	My team fosters a collaborative environment.	81%
	My team fosters an inclusive environment.	83%
	My ideas and contributions are valued within my team.	85%
	I feel free to express myself within my team.	85%
	I am included in subsystem-appropriate decision-making within my team.	85%
Plans tasks	My team plans or planned tasks (e.g., created milestones with due dates).	85%
Established Goals	My team established goals (e.g., created a mission statement).	89%
Meets Objectives	My team meets team-created objectives.	84%
	My team meets advisor-provided objectives.	***68%***
	Earns 75% of milestone credit	95%
	Earns 100% of completion credit	84%

Starting in Spring 2020 the questions “my team established goals” and “my team meets advisor-provided objectives” were added. Originally the establishment of goals was planned to be taken from the team-created mission and vision statements, but this was replaced by a survey question. After consideration, it was also determined that objectives may be student-created (e.g., design specifications) or advisor-provided (e.g., milestones). These were separated as two different survey questions.

Starting in Fall 2020, the question “my team fosters a collaborative and inclusive environment” was split into two questions: “my team fosters a collaborative environment” and “my team fosters an inclusive environment”. This change was intended to further separate the terms that may confound results as “collaborative” and “inclusive” are different measures and may have served to confuse students.

Two quirks of the data bear mentioning. Some students completed the survey more than once. Only the last response from each student was included in the analysis. Several students self-reported that they misread the directions and reported 4 for “strongly agree” and 1 for “strongly disagree.” These students were advised to complete the survey again and the original response was discarded. It is possible that other students made the same mistake but did not repeat the survey.

Discussion

As evidenced above, in the new teamwork assessment the results for each element of the sub-outcomes were reported individually. Sub-outcome results were not combined through averaging, counting the number above a threshold, etc. All sub-outcome results were reported in the annual loop-closing. In contrast, the old peer evaluation method compressed all data to a simple "pass" or "fail". From this, it is evident that the new teamwork assessment method provides much more data than the old peer evaluation method. This is both a pro and a con.

A benefit of the additional data is that it provides insight into which dimensions of teamwork are challenging for students. From this, it is possible to make decisions as to whether the curriculum needs improvement focused on teamwork or if specific teams need (or needed) targeted interventions. A drawback of the additional data is that the reporting is larger and less clear-cut than in the previous method. It is the opinion of the authors that the benefits of this change far outweigh the drawbacks.

Specific to the assessment data provided (Table 5), the 2019-2020 teams showed improvement in the problem areas of "my team has one (or more) student leaders", "student leaders on my team regularly provide leadership to the team", and "my ideas and contributions are valued within my team." Despite the apparent improvement in "project completion", it is likely that this is a result of simplified project requirements due to a COVID-19 mandated shutdown. One area for improvement was creation of a collaborative and inclusive environment. Overall, most scores increased between semesters. This may be a function of more time spent together as a team, learning each other's nuances, and figuring out how to best work toward a common goal. With that stated, the teamwork survey was completed after the March 2020 pandemic stay-at-home orders were issued and courses went online. There is a chance that greater empathy was realized during those trying times, especially considering that the competitions were canceled for 2020.

The 2020-2021 teams responded (Table 7) with higher agreement with "my team fosters a collaborative environment" and "my team fosters an inclusive environment" than the 2019-2020 teams. Overall, the 2020-2021 teams were functioning better in Fall 2020 than the 2019-2020 teams during the similar time period of Fall 2019. This may be a function of the newly implemented "Leadership and Professional Development for Engineers" course, required for all engineering students. This course has a heavy focus on team development, especially regarding conflict-resolution, consensus-building, leadership skills, team charters, and professional ethics. Only a few of the students completed that third-year (i.e., junior-level) course by Fall 2019 with only a single team creating a team contract/charter to be used for resolving team conflicts without involving their faculty advisor. In contrast, almost all of the students completed the course by Fall 2020. Another effect could again be due to the pandemic. The teams were practicing safety protocols which ultimately requires a certain amount of empathy and cooperation. Further data may reveal the effect of the new course vs. any pandemic effects.

While this paper has focused on an assessment survey in the context of capstone projects and specifically CDS teams, this assessment method should be just as viable for any engineering project team anywhere in the curriculum, as long as the project is of sufficient length. For example, course projects that are three weeks or less would likely not allow enough time for

students to rank each survey statement meaningfully. In addition, the non-survey elements (milestones and project completion) can and should be a part of non-capstone projects to be also included in the teamwork assessment.

Conclusions

In this work a new ABET Student Outcome 5 assessment method was introduced for capstone design. The new assessment tool addresses each of the sub-outcomes of ABET Student Outcome 5, allowing for greater distinction of strengths and weaknesses within a team. The assessment method includes both a student survey and instructor-assessed elements. The method is being used in the capstone design course sequence, and the results from three semesters of implementation were reported and briefly discussed.

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