Introduction of electromechanical projects within a Mechanical Engineering Technology Capstone program

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Abstract. Engineering technology capstone experiences are intended to develop student competencies in applying technical and non-technical skill sets. To further this objective, electromechanical projects were introduced within the University of Maine’s two-semester-long Mechanical Engineering Technology (MET) Capstone sequence during the 2016 - 2017 academic year. Of 11 total MET projects completed, 6 projects – merry-go-round-powered cell phone charger, bio-mass pellet mill, haptic floor, press fitting machine with data integration, automation of material handling, and propane-electric hybrid go kart – employed electromechanical systems. Five of the electromechanical projects were completed by MET teams comprised solely of MET students. The sixth electromechanical project, i.e., the propane-electric hybrid go kart, had a multidisciplinary team consisting of one MET sub-team and one Electrical Engineering Technology (EET) sub-team. This paper reviews the MET and EET Capstone sequences, MET student demographics, instructor preparations, the six electromechanical projects, and the five mechanical projects, as well as compares results. Lessons learned and recommended best practices are presented on how to incorporate electromechanical projects into an MET capstone sequence, which by extension should apply to other interdisciplinary capstone projects.

1. Introduction

Mechanical Engineering Technology (MET) capstone experiences are tasked to develop student competencies in applying technical and non-technical skills via the design, implementation, and testing of projects [1]. In 2015, the Accreditation Board for Engineering and Technology (ABET) revised MET program outcomes such that MET capstone projects should ideally be multidisciplinary in nature [2]. The desired multidisciplinary nature of MET capstone projects is further emphasized within the American Society of Mechanical Engineers (ASME) Vision 2030 Phase I Report [3], which states that capstone projects should be multidisciplinary in nature while providing opportunities for MET students to work with students in other disciplines.

The need to educate engineers capable of working on multidiscipline projects is not new. For example, in 1992 Tooker et al. [4] stated that engineering colleges should instill the importance of combining disciplines, making tradeoffs, and develop a multiple discipline mentality. The need for combining engineering disciplines was quantified in 1994, when approximately 83% of engineering capstone programs employed single discipline capstone projects [5]. Despite multiple multidiscipline capstone case studies in the following years (e.g., within engineering
programs across institutions [6], within an engineering program at a single institution [7] [8] [9], between engineering and non-engineering programs at a single institution [10] [11]), Howe & Wilbarger’s [5] 2005 national survey of engineering capstone design courses found that 81% of engineering capstone programs in 2005 employed departmental teams. This 2% improvement in the reduction of single department capstone programs over 11 years indicates that more work remains in order to achieve multidiscipline engineering capstone programs.

This manuscript documents and reflects upon the University of Maine MET program’s progress towards multidisciplinary capstone. These efforts were realized via two distinct avenues: (1) the introduction of five MET projects having significant electromechanical components; and (2) the introduction of an MET-EET multidisciplinary project. Both types of projects are reviewed within this work.

2. Background

2.1 Mechanical Engineering Technology (MET) Program

The University of Maine’s MET program capstone spline consists of 2 courses – MET 464 (2 credits) in the fall semester, and MET 465 (2 credits) in the spring semester – taught via project-based learning. In the fall semester, students attended approximately 20 lectures in various subjects (e.g., engineering analysis and design [12]; team dynamics; oral, written, and graphical communication skills; lean six sigma); work on projects; attend 30-minute-long weekly meetings with the team’s advisor (i.e., one of the co-instructors); and complete two project reports. The first project report must contain a literature review, project definition, and 3 to 5 solution concepts. The second project report documents down selection of the 3 to 5 solution concept to a final design, justification for the down selection, and an analysis of the final design. The second semester consists of 4 lectures, 30-minute-long advisor meetings every week, 30-minute-long cross-advisor (i.e., the instructor who is not their advisor) meetings every other week, two written project reports, and a final presentation. The third overall project report (i.e., the first report of the 2nd semester), concerns the building of the project. The fourth written project report i.e., the 2nd of the 2nd semester) documents testing, operation, or validation of the project. An final presentation is presented by each team of students during the last week of the semester.

In addition to the student team members, key project personnel include: (1) advisor, (2) project sponsor, (3) cross-advisor, and (4) outside faculty as necessary. The advisor is one of the capstone instructors and meets with each team for approximately 30 minutes a week to review progress. Teams have the same team advisor during both semesters. The project sponsor is a person outside of the University of Maine who has the vision for the project. Teams meet with the project sponsor on an ad-hoc basis. Depending on the sponsor organization, a team may meet with one or more than one project sponsor. The cross-advisor is the other capstone instructor and meets with the team every other week during the 2nd semester. If neither the project sponsor, advisor, nor cross-advisor have the requisite technical knowledge, outside faculty are sought with the appropriate skill sets. Each MET student was allocated $150 from the MET department for the project build.
One challenge of adding significant electrical elements to MET capstone projects is the lack of electrical subject matter within the MET curriculum. The MET curriculum consists of 41 total courses (128 total credit hours) of which 4 courses (14 credit hours) specifically address electrical topics. The four courses specifically addressing electrical topics are:

1. **PHY 108 “Technical Physics II”** (4 credits) – electromagnetic topics from a physics perspective;
2. **COS 120 “Introduction to Programming”** (3 credits) – novice-level programming in visual basic;
3. **MET 234 “Mechanical Technology Laboratory I”** (3 credits) – instrumentation;
4. **EET 330 “Electrical Applications”** (4 credits) – alternating current and direct current (AC/DC) circuits, amplifiers, and transducers.

Noticeably missing from the curriculum are courses in microcontrollers, programmable logic controllers, or industrial automation.

Project selection was driven by the two instructors and the students. The instructors solicited project concepts from industry, university labs, the general public, and the students approximately 4 to 6 weeks before the beginning of the fall semester. During the first week of the fall semester, students rank ordered their top three project concepts, which the instructors employed to assemble teams.

### 2.2 Electrical Engineering Technology (EET) Program

The University of Maine EET program capstone spline consists of 3 courses – EET 350 (1 credit) in the spring semester of a student’s junior year, EET 451 (1 credit) in the fall semester of a student’s senior year, and EET 452 (2 credits) in the spring semester of a student’s senior year. In EET 350, students attend 7 lectures (e.g., project management, team dynamics, prototyping), self-select teams of 2 to 3 students per team, research their project, and submit a project proposal. In EET 451, teams of students build their projects, submit supporting documentation (e.g., expanded project proposal, progress reports), and demonstrate proposed specifications on a prototype. In EET 452, students complete the build and disseminate knowledge via final oral and written reports. Students receive no departmental funds for their project and therefore must purchase any required supplies.

### 2.3 Preparations for the multidisciplinary MET-EET project

MET and EET capstone instructors met approximately 3 months before the start EET 350 to discuss the potential MET-EET multidisciplinary project. Topics focused on an appropriate scope for an MET-EET multidisciplinary project, project deliverables for MET and EET capstone courses, oral and written reporting requirements, financial resources, and merging of dissimilar schedules (cf. Table 1). The most difficult tasks were to merge the dissimilar schedules and the selection of appropriate scopes such that if either the MET or EET sub-teams failed to successfully complete their portion, the other sub-team would not be adversely affected. Hence, the MET and EET sub-teams within the multidisciplinary team were assessed separately by MET and EET faculty, respectively. After the capstone instructors reached an agreement, the capstone instructors’ decisions were ratified at departmental and school levels. The entire process required approximately 6 weeks to complete.
Table 1. Comparison of Mechanical Engineering Technology (MET) and Electrical Engineering Technology (EET) capstone splines.

<table>
<thead>
<tr>
<th>Program</th>
<th>Semester (year of student)</th>
<th>Spring (Junior year)</th>
<th>Fall (Senior year)</th>
<th>Spring (Senior year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MET</td>
<td></td>
<td></td>
<td>MET 464 (2 credits)</td>
<td>MET 465 (2 credits)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Define project,</td>
<td>Down selection,</td>
<td>Build</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Literature review,</td>
<td>analysis,</td>
<td>Verify, final</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ideation</td>
<td>final concept</td>
<td>presentation</td>
</tr>
<tr>
<td>EET</td>
<td>EET 350 (1 credit)</td>
<td>EET 451 (1 credit)</td>
<td>EET 452 (2 credit)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Research</td>
<td>Define &amp; propose</td>
<td>Ideation, Build</td>
<td>Verify, Final</td>
</tr>
<tr>
<td></td>
<td></td>
<td>project</td>
<td></td>
<td>presentation</td>
</tr>
</tbody>
</table>

2.4 2016-2017 Student cohort

The fall 2016 MET 464 cohort consisted of 46 male students and 0 female students. Forty five students were MET majors, one student was an MET-EET dual major. On average, the fall 2016 cohort completed the 4 electrical courses, i.e., PHY 108, COS 120, MET 234, and EET 330, approximately 2.5 years, 1.6 years, 0.9 years, and 1.8 years prior to the start of MET 464. Most of the MET students were in their last 2 semesters of the MET program with 76% of the cohort graduating at the end of the spring 2017 semester.

Student grades in the four electrical subject matter pre-requisites were analyzed to determine if there were differences between students’ previous academic performance in electrical or electrical engineering courses. The MET cohort was stratified by the type of project, i.e., electromechanical (EM) or purely mechanical (PM), and analyzed via Analysis of Variation (ANOVA) hypothesis tests within Minitab 17 [13] via the null hypothesis: there was no difference in previous electrical knowledge of students who worked on EM projects and students who worked on PM projects. The analysis resulted in p-values of 0.087, 0.920, 0.561, and 0.141 corresponding to PHY 108, COS 120, MET 234, and EET 330, respectively. Assuming a typical $\alpha = 0.05$ corresponding to a 95% confidence interval, there was no statistically significant difference in electrical knowledge for MET students who worked on EM and PM capstone projects.
3. Projects

After each student rank-ordered their top three project ideas, an MET capstone instructor matched the 46 MET students to 11 teams – 9 four-person teams, and 2 five-person teams. The matching process resulted in all 46 students matched to projects that were one of their top three choices with approximately 46% of students matched with their 1st choice, 37% of students matched with their 2nd choice, and 17% of students matched with their 3rd choice. The 11 projects included the design and manufacture of: (1) a cell-phone charging station powered by a merry-go-round; (2) a propane-electric hybrid go kart; (3) a haptic floor; (4) knitted carbon-fiber composites for structural applications; (5) pellet mill for bio-sourced energy; (6) 4th axis for a Computer Numerically Controlled (CNC) router; (7) automation of material handling; (8) press fitting machine with data integration; (9) feasibility study of 3D printed fixtures and dies for aerospace manufacturing; (10) a boat-launch platform; and (11) a boom mower for high-angle mowing applications. Six projects were sponsored by industry, three projects were sponsored by University of Maine laboratories, and two were sponsored by other entities.

From left to right, Table 2 shows the classification, project number, project description, and relates each project to elements contained within each project with an “X” indicating significant components of the project contained this aspect. Projects were classified as having electromechanical aspects if they employed electrical drives, instrumentation & controls, or microcontrollers & Programmable Logic Controllers (PLCs), which are shown as the three right-most columns in Table 2. The six projects involving substantial electromechanical aspects are shown with a gray background at the top of the table; the five projects without substantial electromechanical aspects are shown with a white background at the bottom of the table.
Table 2. Capstone projects showing relation between project description and elements within each project.

<table>
<thead>
<tr>
<th>Classification</th>
<th>#</th>
<th>Description</th>
<th>Mechanics</th>
<th>Materials</th>
<th>Dynamics &amp; Vibrations</th>
<th>Mechanical Power Transmission</th>
<th>Fluid Power Transmission</th>
<th>Electrical drives</th>
<th>Instrumentation &amp; Controls</th>
<th>Microcontrollers &amp; PLCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electromechanical (EM)</td>
<td>1</td>
<td>Cell-phone charging station powered by a merry-go-round</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Propane-electric hybrid go kart(^1)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Haptic floor</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X^2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Pellet mill for bio-sourced energy</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Automation of material handling</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Press fitting machine with data integration</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X^2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purely Mechanical (PM)</td>
<td>4</td>
<td>Knitted carbon-fiber composites for structural applications</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>4th-axis for CNC machine</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>3D printing for aerospace dies and fixtures (cf. [14])</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Boat-launch platform</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Boom mower for high-angle mowing applications</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\): Project completed by MET-EET multidisciplinary team  
\(^2\): Arduino microcontroller  
\(^3\): ABB Programmable Logic Controller (PLC)

In relation to Table 2, the aspects of a project are defined as:

- **Mechanics** – stress analysis of deformable bodies
- **Materials** – processing and characterization of heterogeneous and composite materials; development of material processing methods
- **Dynamics & vibrations** – analysis of moving bodies, including kinematics and kinetics; consideration of natural frequencies
- **Mechanical power transmission** – design of systems incorporating shafts, belts, pulleys, bearings, and other mechanical power transmission components
- **Fluid power transmission** – design of systems incorporating hydraulic or pneumatic pistons, valves, hoses, pumps, and other elements
- **Electrical drives** – design of systems incorporating electric motors, which were employed either to convert electrical energy to motion or motion to electrical energy
- **Instrumentation & controls circuitry** – design of instrumentation systems (e.g., pressure transducers, strain gauges); design of electrical control systems (e.g., wires, current limiting devices, relays, electrical enclosures)
- **Microcontrollers & Programmable Logic Controllers (PLCs)** – selection, wiring, and programming of Arduino microcontrollers; wiring and programming of ABB PLC.
Table 2 indicates that project #7, automation of material handling project, was unique in that this project did not involve significant mechanics, *i.e.*, static or strength of materials analyses. Whereas project #7 involved an industrial ABB PLC, projects #3 and #8 included hobbyist Arduino microcontrollers.

### 3.1 Additional support for electromechanical projects

To compensate for the MET students’ potentially insufficient electrical backgrounds, each project team developed an *ad hoc* network of electrical subject matter experts. These networks varied by team and in aggregate included EET faculty, a licensed electrician who was a family friend of one of the students, the spouse of an MET student, an instrumentation engineer working on the University of Maine campus, and MET course instructors. Whereas most teams self-diagnosed their knowledge gap and sought help from their advisor to identify an electrical subject matter expert, one team failed to self-diagnose their knowledge gap and failed to reach out to instructor-identified subject matter experts in a timely fashion.

### 3.2 Instructors’ observations

The capstone sequence is critical in that students are exposed to real-world projects within an academic environment. Based upon the instructors’ observations, the major challenges faced by the 11 teams were: (1) similar to major challenges faced in previous years, and (2) distributed evenly between EM and PM teams. Major challenges included underestimating time required to complete tasks, failing to complete tasks in a timely manner, under-performing team members, team members not addressing under-performing team members, and managing inter-team conflict. The challenges facing EM and PM were similar in type, severity, and frequency.

### 3.3 Average student effort by team and earned grades

Average student effort by team, as shown in Figure 1, was calculated by summing the total number of hours self-reported by each student within a team and dividing by the total number of students on that team. The average student effort by team was then summed across each type of project and divided by the number of teams to calculate a grand mean within EM and PM projects. A sample standard deviation for the average student effort by team was also calculated. The grand mean for EM projects was 178 hours with a standard deviation of student effort of 103 hours. The grand mean for PM projects was 126 hours with a standard deviation of 25 hours.
Figure 1. Average student effort by team and type of project. Average student effort by team is shown via white-colored circles. The grand mean for each type of project is shown via gray-colored circles. The vertical error bars indicate one standard deviation above and one standard deviation below the grand mean.

Grades in the first and second semesters were analyzed to determine if students within EM and PM projects performed differently. As shown in Figure 2, first semester EM and PM teams performed fairly similar with students on EM and PM projects earning approximately 3.39 and 3.23 average grade points of a possible 4.00 grade points, respectively. The 0.16 greater grades earned by students on EM projects than students on PM projects was statistically insignificant with an ANOVA p-value of 0.483. In the second semester, students on EM and PM teams earned 3.60 and 3.28 grade points of a possible 4.00 grade points, respectively. The 0.32 grade point differential between EM and PM teams was statistically significant with an ANOVA p-value of 0.037.
4. Discussion

4.1 Self-efficacy and task value

In an academic setting, self-efficacy is defined as a student’s belief that they can successfully complete the assigned task [15]. Self-efficacy has been hypothesized to influence a student’s choice of activities, effort expended at the chosen activities, and persistence [16]. In contrast to self-efficacy, task value addresses the questions of if a student wants to do a task and why [17]. Task value has been further decomposed into four categories [17]:

- Attainment value – personal importance to student to do well
- Intrinsic value – enjoyment or interest in the task
- Utility value – alignment of task with a student’s future goals
- Cost – the negative effects of engaging in a task, e.g., loss of time, overly-high effort, stress

Even if a student believes they can accomplish a task (i.e., high self-efficacy), a task with low value will not be attempted. The performance of a student depends upon the student’s self-efficacy and the value the student assigns the task [18].

As this study administered neither self-efficacy nor task value surveys to students, it is impossible to establish a correlation between self-efficacy, task value, and observed performance in either the first or second semesters. However, anecdotal observations by both MET capstone instructors suggest that self-efficacy and task value contributed to the spectrum of observed student performance and should be included in any similar future studies.

4.2 Recommendations

This study considered two topics of interest to capstone instructors: (1) inclusion of subject matter outside of the capstone students’ educational backgrounds, and (2) introduction of a
multidiscipline MET-EET capstone project within an MET capstone course. Regarding the inclusion of electrical engineering subject matter within an MET capstone course, the recommendations from this study include:

- Examine students’ pre-requisite courses to determine potential student knowledge gaps;
- Identify potential subject matter experts prior to the start of capstone;
- Notify students prior to project selection as to the electromechanical nature of the project;
- Electromechanical projects within MET capstone programs should contain mechanical aspects near the chronological start of a project such that students have the opportunity to become comfortable with the new subject material; and
- Encourage early prototyping to identify and address gaps in student knowledge.

Regarding the introduction of a multidiscipline capstone project, the recommendations from this study include:

- Begin the planning process with instructors from both capstone courses at least one semester before the start of the project;
- The planning process should account for project scope, what ABET outcomes are required within each course, what course(s) will each student attend, budgeting, and oral and written reporting;
- Determine dependencies in grading rubrics. For example, if the MET sub-team failed to complete a task, what were the consequences to the EET sub-team; and
- Instructors of both programs should routinely communicate.

4.3 Next steps

While this study indicates that electromechanical content can be included within MET capstone programs and that MET-EET multidisciplinary capstone projects are possible and beneficial to students, there are multiple questions remaining. The suggested next steps include:

- Quantify and analyze the roles of self-efficacy and task value with electromechanical projects within an MET capstone program;
- Increase the number of multidisciplinary capstone projects and the diversity of disciplines within the engineering college at the University of Maine; and
- Encourage a follow-up survey concerning engineering capstone programs to quantify the adoption of multidisciplinary engineering capstone projects and drivers and inhibitors to doing so.

5. Conclusion

The University of Maine Mechanical Engineering Technology (MET) program introduced six electromechanical (EM) projects with the MET capstone engineering spline during the 2016-2017 academic year. Five of the EM projects were completed by teams of MET students; the sixth EM project was an MET-EET multidisciplinary project. An analysis of prior academic performance of students on EM and purely mechanical (PM) projects indicated that there was no statistically significant difference between students on EM and PM teams. Within the limitations of this study, it was observed that:

- MET capstone students were capable of completing EM capstone projects,
Students working on EM and PM projects had similar levels of electrical and electrical engineering knowledge;
Students working on EM projects self-reported approximately 40% more hours than students working on purely mechanical (PM) projects,
Students completing EM projects earned grades that were marginally better to 10% better than the grades of students completing PM projects, and
MET-EET multidisciplinary projects were feasible.

Based upon these results, the University of Maine MET program will continue to incorporate EM subjects into MET capstone projects and expand the number of multidisciplinary capstone projects.

6. References


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