The Write Background Makes a Difference: What Research and Writing Skills can Predict about Capstone Project Success

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Capstone design is an excellent opportunity for students to practice high-level research skills such as formulating scientific argument, conducting literature reviews, interpreting high-quality sources, as well as writing abstracts, executive summaries and advanced reports. Students start with varying levels of proficiency in these skill domains, and progress at different rates toward mastery. The Capstone Design Program at Northeastern University combines both industrial and mechanical engineering students (IE and ME). Their unique major-specific backgrounds provide opportunities to observe differences in the way these two disciplines approach their associated research and writing tasks. Seven years of data on writing and project grades for 268 teams in the Senior Capstone Design course were studied in detail to identify patterns and differences in the ability of teams to master high-level writing skills within each major and apply them to capstone work. Correlations were also sought between these skills and final project quality to determine whether advanced research and documentation competencies translate into commensurate designs. The answer is dependent upon which factors are considered. Both disciplines showed improvement in abstract writing, with 75% of all teams having acceptable abstracts by the third of four reports, as measured by a standard validated scoring rubric. Across ME and IE, only 30% of the teams were initially able to produce acceptable literature reviews. However, mechanical engineering teams started at an overall higher level of proficiency in their ability to choose and apply quality references and produce acceptable literature reviews, while industrial engineering teams tended to be more proficient initially at organizing ideas and applying project management tools. Initial results indicate that the ability to perform quality literature reviews early in the capstone process is positively correlated with later project success. While the organizational and project management abilities of the industrial engineering students serve them well in conveying their project plan at the outset, there is evidence that this propensity toward early organization is associated with some reluctance to adjust and –in some cases– resistance to research in new directions. While administrative prowess is commendable, any associated inflexibility can be unproductive when projects require adjustment and call for new research directions. This work evaluates profiles that have emerged in each major in terms of strengths and roadblocks related to high-level research and writing skills and associated project outcomes. Recommendations will be made to reinforce the productive patterns inherent to each major and shore up skills that can benefit from additional guidance in the areas of background research, organization, and writing.

Introduction

Assessments from capstone courses can be used to determine where the curriculum may need to be changed or reinforced, or where additional practice in high-level skills is needed.[1] According to a past National Design Survey, 87% of capstone programs surveyed cover written communication while 83% address oral communication and 73% teach project management topics.[2] Paretti also discussed a number of best practices for teaching communication in capstone design, and places particular emphasis on instructor actions that promote better communication. One practice was to explicitly connect the required content and format of a given document with how the information was going to be used, for example to evaluate the design, offer a progress update, or to provide documentation of intellectual property.[3]

The Writing Task. Writing tasks can be classified in terms of the level of abstraction required for the task. High-level skills such as scientific and academic argument and analysis can be developed and assessed during Capstone Design.[4] Capstone students must be able to connect their work to the available body of knowledge on the topic, outline current best practices, use existing theory to support the legitimacy of their work, and present their experimental data in a way that validates their design choices. Moreover, students must be able to write for an audience that is educated at a high level but is not necessarily familiar with the specifics of their project.

Furthermore, students must develop the ability to continually revise and adjust their writing in order to incorporate new information while still remaining focused on the goal of the project. They must not only recall information that they have learned previously and draw upon existing sources, but also be able to make inferences and deductions based on that information in relation to new data they have collected, discovered, or developed. The act of writing about the design process is crucial, as it helps solidify ideas, document the process, identify areas of weakness in reasoning, and forces students to justify their design decisions.[5]

***Core Writing Skills*.** There are a number of core writing skills that students must master in order to convey their research processes and design decisions. Yalvac et al. identified a number of skills that are required by upper-level students including concise writing, appropriately using visual information such as figures and tables in conjunction with text, synthesizing information from multiple sources, developing organizational structures for long reports, and correctly citing sources.[6] In this current work, concise composition is judged by the ability of students to write abstracts that concisely and directly summarize the design process and project. Organization is specifically evaluated, and although students are not given a prescribed outline they must follow, they are guided and provided advice about possible organizational structures. A literature review is required in the background section of their report, which can assess their ability to synthesize information from outside sources. The students are also specifically evaluated on their ability to select quality sources and cite them properly. In design courses, students can often be shown parallels between the fact that design problems have no one set solution and the fact that there may be multiple ways to effectively write about designs. Core writing skills and the core analysis and design skills must be developed in tandem for success in both.[7]

***Fixation Propensity*.** Capstone design is inherently an open-ended problem. Although the teams are composed of senior level students, their exposure to open-ended problems varies. Students in different engineering disciplines may have varying amounts of practice in solving these types of problems and may have a wide range of ability, confidence in and inclination to explore and develop alternative solutions. Accordingly, some fixate on early solutions or a singular suggestion made by a faculty advisor.[8][9][10] This fixation can also occur in the writing process, as students can cling to an early plan and/or report that is poorly organized or that is focused on the wrong argument. Likewise, students may resist the notion of revising a report that is well organized when circumstances have changed. Students who become fixated on what they have already planned and written may not make required adjustments based on feedback and thus do not show progression toward achieving specific essential writing and project goals. The relationship between writing fixation and design inertia [9] is one that will be further explored.

Course Details

Term Schedule. Capstone Design in the Mechanical and Industrial Engineering Department at Northeastern University is a two-semester sequence. The stated goal is to have a working prototype or implrmented solution to their chosen project by the end of the second semester of the sequence. Projects may be proposed by faculty, industry sponsors, or students. All projects are vetted and –as much as possible– comparably scoped by the capstone coordinators, who also serve as the instructors of record for the course. As seen in Figure 1 below, mechanical engineering students take the first course (Capstone 1) in one of the two summer semesters (Summer 1 or Summer 2) and the second course (Capstone 2) in either Fall or Spring. One cohort is scheduled for Summer 1, with six months of co-op intervening, followed by Capstone 2 in the Spring of the next year. The second ME cohort has Capstone 1 in Summer 2 and then moves directly into Capstone 2 in the Fall of the same year. For the industrial engineering students, one cohort follows the Summer 1–intervening co-op–Spring sequence. The other cohort has Capstone 1 in the Fall semester and Capstone 2 immediately following in the Spring of the subsequent year. Thus, while the IE students are in two separate groups for Capstone 1, they all take Capstone 2 together. Because of the difference in the scheduling of the Fall and Summer terms, this occasionally leads to slight differences in the timing and exact details of assignments. For example, the Fall-Spring IE sequence may not submit a report as close to the start of Capstone 2 as the Summer1-Spring groups, as they had turned in a report only three weeks prior.

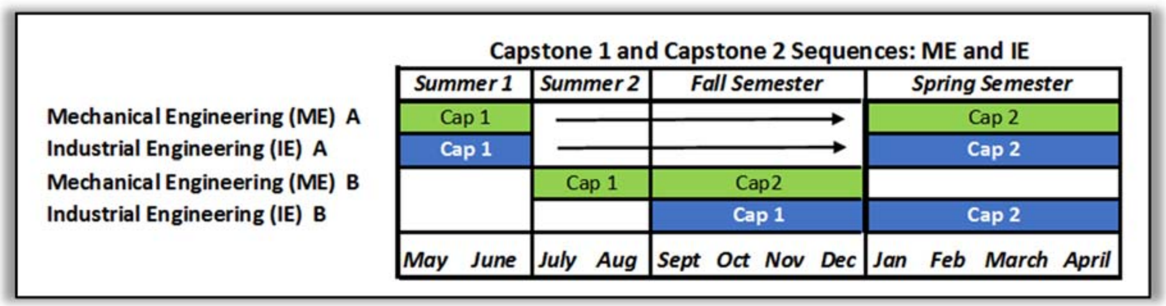

Figure 1. Capstone Sequences for each Major and Division

Demographics. The study evaluated 268 groups with 1238 total students over 7 terms. In the complete data set, 20% of the students were female, 80% male. Additionally, 21% of the students were international students. The relative number of international students increased slightly over the course of the study, but no significant differences were found among the groups in terms of outcomes associated with the number of international students by major. All students were seniors in their last or second to last term of study.

Process Assessment. Capstone success is evaluated based on a number of factors. Technical writing is assessed by a trained engineering professor from the major who is part of the capstone instructor team but who is not associated with any particular team. This provides the teams with detailed feedback from a knowledgeable impartial engineer. Typically, three reports are graded in detail by the writing instructor. The first report is written at the end of the first capstone term. The Capstone 1 report is expected to contain an abstract, a well-developed problem statement, a thorough literature review, initial design ideas or solution paths, and a clear discussion of project management and plan for moving forward.

The second report, Capstone 2 Report 1, is written at a point approximately 1 month into Capstone 2. This report is expected to expand on the previous report, incorporate feedback from an external design review, and clearly select a design solution with which to move forward. The third Capstone 2 Report is written at a point two thirds of the way through the Capstone 2 course. Capstone 2 Report 2 is expected to contain analysis of the chosen solution and/or testing and verification as appropriate, as well as a detailed description of the final design.

The fourth, final report at the end of Capstone 2 is used for overall assessment, but is not given a separate technical communication grade. The writing instructor also provides grades for an Executive Summary that is written at a point 3 weeks from the end of term, the poster presentation for the final presentation day, and the oral presentations given at the same time as the first three reports.

***Solution Evaluation*.** Although IE teams tend to develop solutions such as database schemes, facilities layouts, process improvements and organizational structures, the term 'prototype' is used to refer to all capstone solutions to simplify taxonomy. The completeness of the solution or prototype is assessed on a validated 10-point scale as presented previously.[11] This prototype score is determined in conjunction with the Executive Summary, three weeks prior to the end of entire project. A potential total of 5 points is given for the completeness of the prototype at that point. An additional 5-point scale is applied to assess completeness of the testing or validation of the prototype.

Methodology

Graded feedback from the 268 written reports was examined to determine whether groups had achieved certain key high-level skills. The particular criteria of interest were:

- **Abstract:** The ability to write a concise abstract that clearly summarizes the problem, method and work accomplished to date.
- **Organization:** The ability to present information in a logical fashion that is easy for the reader to follow and makes direct connections to relevant aspects of the project.
- **Project Management:** The ability to outline, develop, choose, and elucidate a coherent and plausible plan of action for the project.
- **Background:** The ability to write a proper literature review that clearly outlines each necessary theory in addition to discussing and critically evaluating the shortcomings of existing solutions to the problem.
- **References:** The ability to find and properly cite quality refereed sources that support the argument being made, method being applied, or conclusion being drawn.
- **Testing/Analysis**: The ability to develop and explain experimental studies, technical principles, and/or mathematical models to validate a chosen design.

In addition to testing differences between the majors on the factors listed above, the success of teams on these particular criteria were examined using Pearson's Product Moment Analysis. This was done to determine whether correlations existed between the above criteria and outcome measures, such as the prototype scores. Teams were considered collectively, separated by term and discipline, and also individually. Specific research questions considered were as follows:

- Are there certain proficiencies that one discipline exhibits versus the other?
- Does the proficiency of particular disciplines change at different rates?
- Do certain proficiencies correlate more strongly with project success?

Results

The first and second reports were assessed using the specific criteria seen in Table 1 below. For each assessment item, a value of 1 meant that the report fully met that criteria, a value of 0.5 meant that the criteria was partially met, and a value of 0 meant that the criteria was not met. The highlighted criteria represent high-level writing and analysis skills that were the particular focus of the current study. The third report had slightly different criteria, as seen in Table 2. At that stage in the Capstone process, the focus shifts away from project management and is directed toward clear presentation of the final design and analysis of that design. Again, the highlighted criteria considered high-level research and analysis skills that are being currently studied.

Table 1. Criteria for Capstone 1 Report and Capstone 2 Report 1

Proper cover page and fonts
Abstract which summarizes problem, method, solutions to date
Table of contents
Good organization; clear and logical flow of ideas
Images, equations, and/or tables, properly formatted and discussed
Endnotes and proper references, good quality sources
Third person, minimal grammar, spelling, or wording errors
Problem Statement clear and easy to follow
Background section clearly organized, patents and papers discussed and described
Initial designs/approaches described clearly
Project management information clear
IP section included with all correct subsections

Table 2. Criteria for Capstone 2 Report 2. Added items are presented in bold.

Proper cover page and fonts
Abstract which summarizes problem, method, solutions to date
Table of contents
Good organization; clear and logical flow of ideas
Images, equations, and/or tables, properly formatted and discussed
Endnotes and proper references, good quality sources
Third person, minimal grammar, spelling, or wording errors
Problem Statement clear and easy to follow
Background section clearly organized, patents and papers discussed and described
Initial designs/approaches described clearly
Final Design presented with overview, then subsections
Testing/Analysis thoroughly discussed
IP section included with all correct subsections

The results of the report grading were examined for 10 offerings. Capstone cohorts are identified by their Capstone 2 term; thus, an ME class labeled 'Fall 2012' finished Capstone 2 in the Fall of 2012. The grading results were first examined by aggregating the groups for each term. The ME and IE teams were considered separately. Teams were also examined individually, with all terms aggregated and individual group results considered, again comparing ME versus IE teams.

Capstone 1 Report: ME and IE. Table 3 shows results for the Capstone 1 reports by term, with all the groups considered collectively for that term. The percentage of teams who achieved each objective criterion completely is shown. ME teams ranged from 57% to 88% achievement on abstract writing, while IE teams ranged from 25% to 75%. The IE teams in Spring 2016 earned the highest percentage of organization scores, with 98% of the teams meeting this criterion. In general, however, IE teams were much less likely to use quality references and write effective background literature reviews. For both disciplines, project management proficiency varied widely term by term. This may reflect variations in coordinator, project type, or other factors.

Table 3. Capstone 1 Report: Percentage of teams achieving each component.
75%=acceptable, shading code: 70 ≤ [ ] < 80 ≤ [ ]

ME Teams	% of teams achieving goal				
Term	Abstract	Proj Mgmt	Organization	Background	References
Spring 2012	88.9	61.1	72.2	50	61.1
Fall 2012	63.2	57.9	63.2	47.4	73.7
Spring 2013	77.3	90.9	63.6	40.9	68.2
Fall 2013	75	56.3	75	37.5	62.5
Spring 2014	57.1	90.5	81	66.7	76.2
Fall 2014	63.6	68.2	50	27.3	54.5
Spring 2015	77.3	77.3	68.2	36.4	59.1
Fall 2015	79.2	79.2	75	41.7	54.2
Spring 2016	81.8	72.7	72.7	50	54.5
Fall 2016	73.7	78.9	68.4	36.8	31.6

IE Teams	% of teams achieving goal				
Term	Abstract	Proj Mgmt	Organization	Background	References
Spring 2013	70	50	60	40	60
Spring 2014	25	75	87.5	12.5	12.5
Spring 2015	60	80	86.7	33.3	46.7
Spring 2016	53.8	92.3	92.3	30.8	61.5

The averages and standard errors shown in Figure 2 below outline some patterns for each of the writing components in the Capstone 1 report, illustrating that overall both majors were similar in their project management competencies. While the average of the IEs was much lower for abstract composition, a single class from Spring 2014 brought the average down appreciably. This group was also much lower in other areas, pointing to the need for consistently guiding, modeling, and emphasizing all aspects of the writing component.

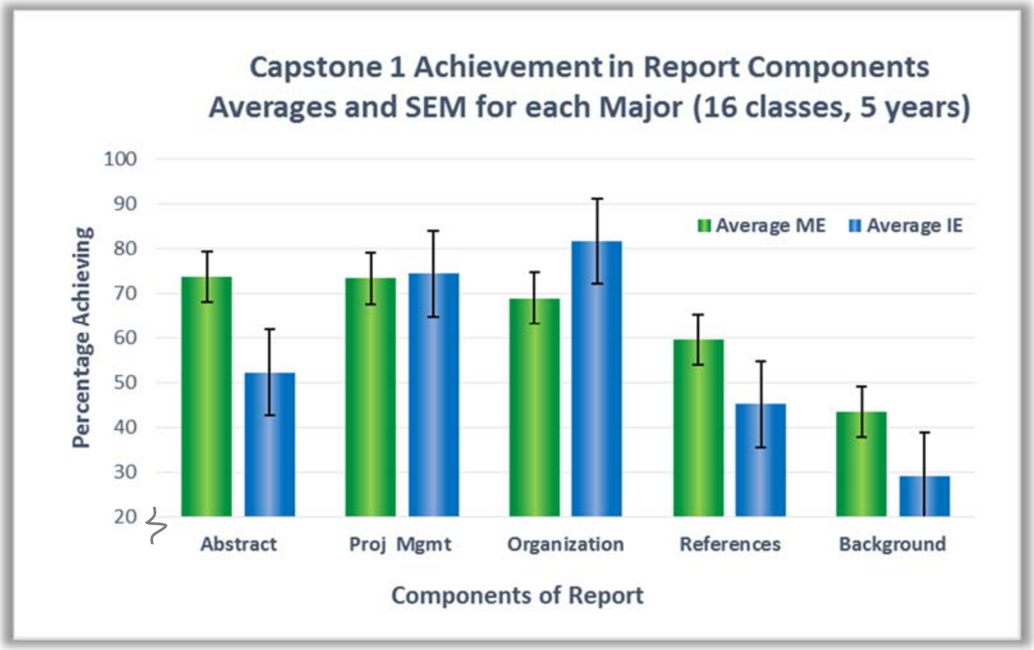

Figure 2. Achievement in report components at the end of Capstone 1 for both Mechanical and Industrial Engineering majors, average and SEM.

Capstone 2 Report 1: ME and IE. Aggregate results for Capstone 2 Report 1 are shown in Table 4 and Figure 3 below. Fewer IE teams are included in this particular group because for Capstone 2, IE teams who had Capstone 1 in the Fall term, the time between the Capstone 1 Report and Capstone 2 Report 1 was short enough that it was judged that the students did not have enough time to generate additional new material. In recent terms, the schedule has been adjusted to prevent this, since students have been shown to benefit from the additional point of feedback and opportunities to undergo revisions to both the project and the report.

Table 4. Capstone 2 Early Report 1: Percentage of teams achieving each component. 75%=acceptable Shading code: 70 ≤ [ ] < 80 ≤ [ ]

ME Teams	% of teams achieving goal				
Term	Abstract	Organization	Proj Mgmt	Background	References
Spring 2012	78.6	64.3	[0]	85.7	64.3
Fall 2012	77.8	72.2	83.3	61.1	55.6
Spring 2013	63.2	73.7	47.4	73.7	68.4
Fall 2013	77.3	77.3	95.5	68.2	77.3
Spring 2014	81.3	87.5	93.8	87.5	75
Fall 2014	76.2	76.2	90.5	71.4	90.5
Spring 2015	72.7	68.2	81.8	54.5	81.8
Fall 2015	90.9	81.8	77.3	81.8	77.3
Spring 2016	87.5	79.2	83.3	70.8	79.2
Fall 2016	81.8	77.3	90.9	81.8	72.7

Table 4 (*continued*). Capstone 2 Early Report 1: Percentage of teams achieving each component. 75%=acceptable, shading code: 70 ≤ [ ] < 80 ≤ [ ]

IE Teams	% of teams achieving goal				
Term	Abstract	Organization	Proj Mgmt	Background	References
Spring 2012	12.5	62.5	[0]	25	37.5
Spring 2014	75	50	62.5	37.5	37.5
Spring 2016	61.5	84.6	92.3	69.2	38.5

IE teams have comparable, yet more variable, organization skills to the MEs at this point, which is nearing the solution-path segment of Capstone. However, some IE groups seem reluctant to adjust their previous report to incorporate new information. This necessarily reflects the associated inertia of the project path as well, which may lead to lower final design scores.

For the ME teams in the first Capstone 2 report, each term had 63% or more of the teams writing a quality abstract, while for the IE teams this varied between 12.5% and 75%. Again, the IE teams on average were less proficient in using references properly and writing adequate literature reviews. Other than Spring 2014, when only 50% of the IE teams achieved strong organization, the rest of the teams, both IE and ME, had similar percentages of teams achieving the goal.

An anomaly was seen in Spring 2012 when none of the ME or IE teams presented project management information in the Capstone 2 Report 1. Those values of 0 are not included in the computations. This was due to a miscommunication on the part of the coordinator. Otherwise, project management scores varied term to term, but by less than in the Capstone 1 Report.

Another finding of note reveals a high level of variability across all proficiency levels for industrial engineering teams. Some did quite well, while others still had some more potential to achieve. This is especially seen in Table 4 above and Figure 3 below.

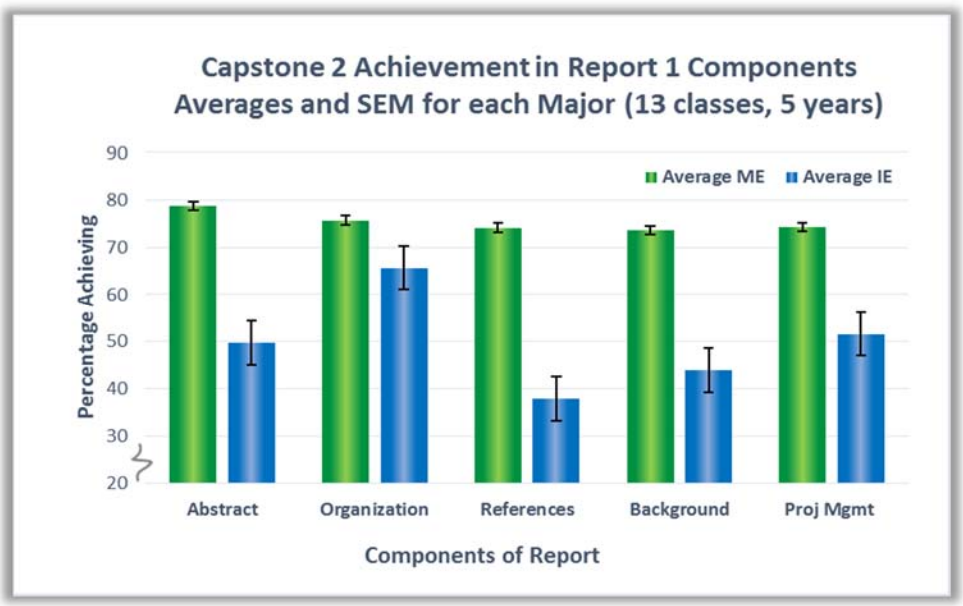

Figure 3. Achievement in report components early in Capstone 2 Report 1 for both Mechanical and Industrial Engineering majors, average and SEM.

Capstone 2 Report 2: ME and IE. Table 5 below shows results for Capstone 2 Report 2, which occurred just after the midpoint of the second capstone semester for all teams. For this report, Testing/Analysis was studied in place of Project Management. The Testing/Analysis scores were higher overall for ME teams. Refer to Figure 4 for presentation of the means for both majors.

Table 5. Capstone 2 Report 2: Percentage of teams achieving each component. 75%=acceptable, shading code: 70 ≤ [ ] < 80 ≤ [ ]

ME Teams	% of teams achieving goal				
Term	Abstract	References	Organization	Background	Testing/Analysis
Fall 2012	64.3	92.9	92.9	85.7	78.6
Spring 2013	73.7	78.9	78.9	89.5	52.6
Fall 2013	84.2	73.7	84.2	78.9	84.2
Spring 2014	77.3	90.9	81.8	95.5	81.8
Fall 2014	70.6	76.5	76.5	70.6	52.9
Spring 2015	76.2	90.5	85.7	85.7	85.7
Fall 2015	77.3	72.7	77.3	59.1	45.5
Spring 2016	87.5	83.3	87.5	91.7	79.2
Fall 2016	83.3	83.3	87.5	87.5	58.3
Spring 2017	86.4	90.9	81.8	95.5	72.7

IE Teams	% of teams achieving goal				
Term	Abstract	References	Organization	Background	Testing/Analysis
Spring 2012	50	75	62.5	75	12.5
Spring 2013	90	60	50	20	40
Spring 2014	87.5	50	50	50	75
Spring 2015	53.3	66.7	73.3	60	53.3
Spring 2016	92.3	92.3	69.2	69.2	69.2

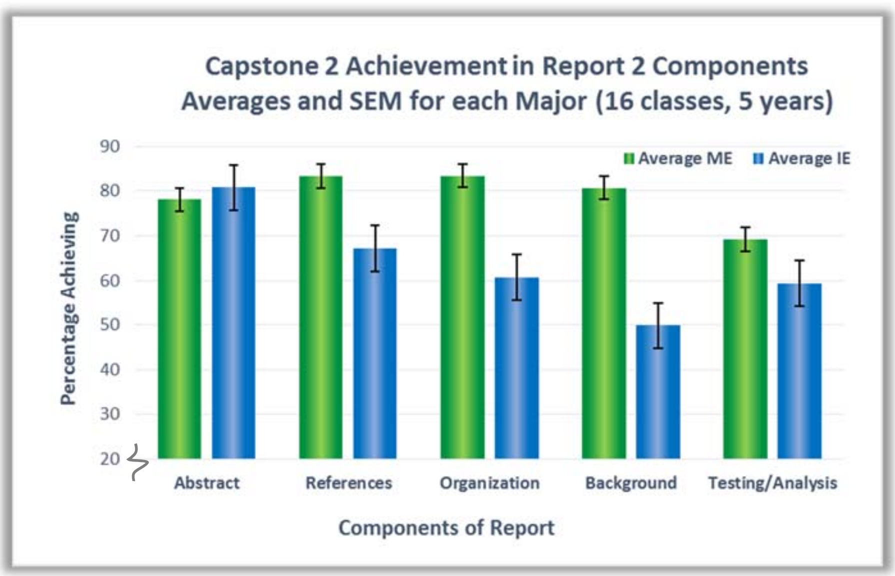

Figure 4. Achievement in report components midway through Capstone 2 for both Mechanical and Industrial Engineering majors, average and SEM.

At this juncture, abstract scores for the ME and IE teams were more on par with each other than in previous reports. The organization scores were slightly lower for IE teams. The reference and background scores for the IE teams improved over the previous reports, but in several cases the averages still did not reach the same level as those of ME teams.

Progression over Time: ME and IE. The average percentages of component goals achieved over all terms are summarized in Figures 5 and 6 below. These figures outline progression during the Capstone sequence for the mechanical engineering and industrial disciplines, respectively, in each of the writing components considered. Report 2 in Capstone 2 does not require a project management plan but does need to outline testing and analysis of the chosen solution(s).

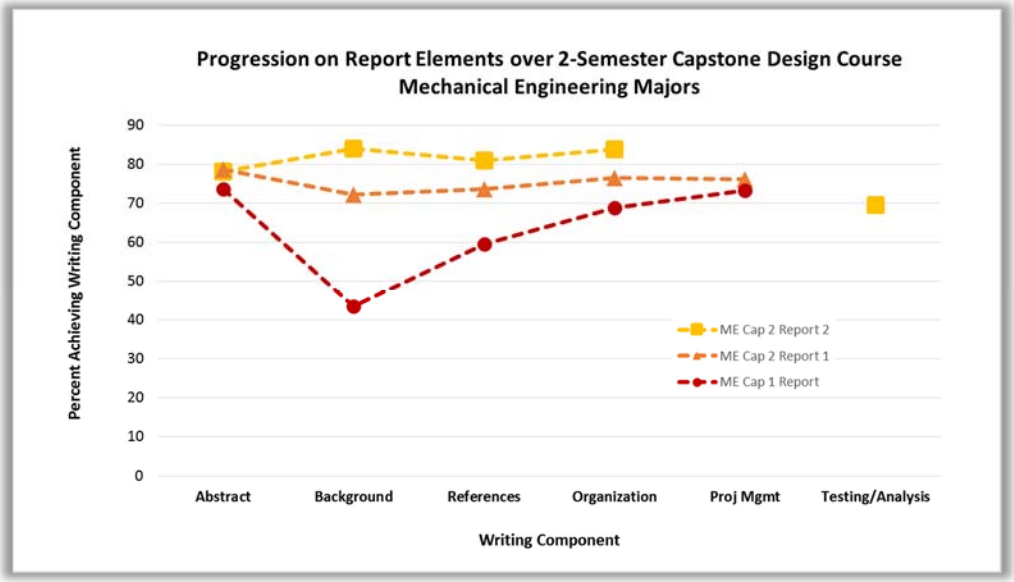

Figure 5. Average ME achievement level for each representative writing element by term. Testing/Analysis was evaluated instead of Project Management at this stage of Capstone.

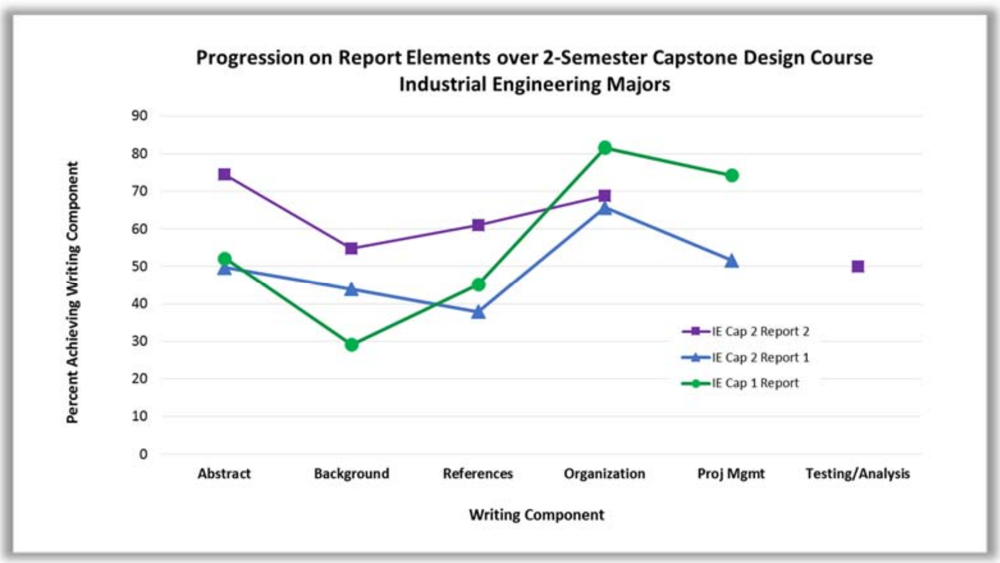

Figure 6. Average IE achievement level for each representative writing element by term. Testing/Analysis was evaluated instead of Project Management at this stage of Capstone.

As seen in Figures 5 and 6 above, ME teams on average do better on abstracts, references, and background for the first report, whereas the IE teams excel at organization. Both majors were similar in terms of project management. By the Capstone 2 Early Report 1, 72% or more of the ME teams had achieved all of the criteria. IE teams improved their background material, including literature review, but showed lower achievement in all other components. This could be an artifact of the fewer data points for this report, as not all IE groups were required to write this particular report. However, this could also point to discipline-specific challenges in integrating existing work in the literature and in industry with their own work. Finally, for Capstone 2 Report 2, the ME groups on average had either maintained or increased their overall proficiency in achieving the criteria. IE teams also improved in most criteria over previous reports, but did not reach the same level of achievement as the ME teams.

Pairwise Factor Correlations. Pearson's Product Moment correlations were computed and examined using the aggregate scores for each term for the 3 report submission milestones. The most notable relationships are included in Tables 6, 7, and 8 to follow. Shaded cells represent negative correlations, and ***bold italics*** results depict significant correlations at the α=0.05 level. Only strong correlations ($R^2 > 0.70$) and moderate correlations ($R^2 > 0.29$) were reported.[12]

For the first paper in Capstone 1, the key correlations are presented in Table 6 below. Strong positive correlations were seen between the ability to present background research and he ability to write abstracts and appropriately use high quality literature sources. Good quality references were also positively correlated with abstract writing ability. Negative correlations were seen, but none were statistically significant at α=0.05.

Table 6. Pearson's *R* values for aggregate scores, Capstone 1 Report

PAIRED COMPONENTS	R^2	*P* (α=0.05)
Background/Abstract	***0.83***	***0.006***
Background/References	***0.76***	***0.02***
References/Abstract	0.60	0.09
Organization/Abstract	-0.47	0.20
Prototype/Abstract	-0.47	0.20
Prototype/References	-0.41	0.43
References/Organization	-0.34	0.37
Background/Organization	-0.31	0.32
Shaded Cells = Negative Correlation	***Bold Italics = Significant correlation***	

Table 7 below presents correlations for the aggregate scores from the first report in Capstone 2. Strong positive correlations were seen between the ability to write background literature reviews and the ability to use quality sources correctly and write abstracts. Moderate positive correlations were seen between abstract writing and organization, abstract writing and quality references, references and organization, and background material and organization. At this point in the course, students have a larger amount of material to write about, and organization becomes more curcial. A significant negative correlation was seen between prototype scores and organization. This may represent those who focus more strongly on the prototype to the detriment of the written communication or those who may be fixated on the original plan to the detriment of the project. Other negative correlations were not statistically significant.

Table 7: Pearson's R^2 values for aggregate scores, Capstone 2 Report 1

PAIRED FACTORS	R^2	P (α=0.05)
Background/Reference	***0.74***	***0.02***
Background/Abstract	***0.71***	***0.03***
References/Abstract	***0.68***	***0.04***
Abstract/ Organization	0.36	0.34
Background/Organization	0.62	0.08
References/Organization	0.58	0.10
Prototype/Organization	***-0.78***	***0.01***
Prototype/Background	-0.47	0.18
Prototype/References	-0.41	0.27
Prototype/Abstract	-0.40	0.32
Shaded Cells = Negative Correlation	***Bold Italics = Significant correlation***	

Table 8 presents the results for the second report in Capstone 2. There are positive correlations between background material and organization, between background and references, and between references and organization. At this stage, students should have fully completed their background research and thus should be using it to inform their design and the rest of their report. There is a moderate negative correlation between prototype score and organization.

Table 8: Pearson's R^2 values for aggregate scores, Capstone 2 Report 2

PAIRED FACTORS	R^2	P (α=0.05)
Background/Organization	***0.75***	***0.008***
Background/References	***0.66***	***0.03***
References/Organization	***0.56***	***0.07***
Prototype/Organization	***-0.59***	***0.05***

Results for Individual Teams across Components. In addition to aggregating the groups for each term, results for individual teams were examined internally for key correlations as well and are discussed below.

Capstone 1 Report, Inferential tests. For the first capstone paper, two-tailed *t*-tests were used to compare ME and IE groups in terms of their performance on the high-level writing skills. All analyses were conducted at the α=0.05 level of significance. No significant differences were found between the two disciplines in their ability to write abstracts or to skillfully present their project management. The IE teams were better than the ME groups in prototype score, and the difference was nearly significant at p=0.06. IE teams were also slightly better than ME terms in terms of organization skill, and again the difference approached significance at p=0.07.

Statistically significant differences were found between the disciplines in their ability to conduct background literature reviews and their ability to seek out and properly use high quality references. Accordingly, ME teams fared better in their background material (p=0.02) and in their use of references (p=0.008) in this first report.

Capstone 2 Report 1, Inferential tests. For the second report, which is the first report due in the second capstone semester, no significant differences emerged between IE and ME teams in terms of abstracts, organizational ability, background literature, and project management discussion. As noted, there were fewer IE teams who completed the second report, because teams in the Fall-Spring sequence were not asked to do the early Capstone 2 report. For the total number of high-level skills, the ME teams were slightly better than the IE teams, and the difference was nearly significant (p=0.07). The only significant difference found was that the ME teams were better at using high quality references at this stage (p=0.001).

Capstone 2 Report 2, Inferential tests. For the third report, which is due at a point two thirds into the second term, there were no significant differences found between ME and IE teams in terms of abstract writing competence and the ability to discuss testing and analysis. For organization and reference skills, ME teams were slightly better than IE teams, but the differences were not significant (p=0.07 for organization and p=0.06 for reference skills.) The ME teams exhibited statistically more total high-level skills than the IE teams in terms of mastering the fundamental writing components (p=0.01). For the background literature review, ME teams fared better than IE teams (p=0.0007). In terms of final prototype scores, the IE teams performed better than the ME teams (p=0.02). This group contains more IE students who had completed all three reports, rather than only two, and this may provide more points of feedback which can translate to improved designs.

For the individual team data, correlations were sought between the various high-level writing skills, the prototype scores, and the total number of high-level writing components mastered in capstone reports. Table 9 shows the results for the first paper at the end of Capstone 1. Only correlations with R^2 values >0.29 are shown. As expected, each of the individual high-level skills are correlated with the number of total high-level skills exhibited. However, the ability to conduct and compose literature reviews (background) and use high quality references properly were most strongly correlated. This is not surprising as they are not entirely independent of each other. There were also moderate positive correlations between the ability to write background material and the ability to use references, and between background work and organizational skill.

Table 9. Pearson's R^2 values for Capstone 1 Report, Individual Teams

PAIRED FACTORS for INDIVIDUAL TEAMS	R^2	P (α=0.05)
Background/Total high-level skills	0.69	< 0.001
References/Total high-level skills	0.64	< 0.001
Organization/Total high-level skills	0.61	< 0.001
Project management/Total high-level skills	0.55	< 0.001
Abstract/Total high-level skills	0.53	< 0.001
Background/References	0.37	< 0.001
Background/Organization	0.36	< 0.001

Table 10 displays the results for the first paper at the beginning of Capstone 2. Again, only correlations with R^2 values >0.29 are shown. Background writing ability was strongly correlated with the total number of high-level behaviors and moderately correlated with organization.

Organization was also moderately correlated with total high level behaviors and with project management. Project management seemed to be positively correlated with several factors. This may indicate more proficiency at clearly describing their project strategy at this point in the capstone design process.

Table 10: Pearson's R^2 values for Capstone 2 Report 1, Individual Teams

PAIRED FACTORS for INDIVIDUALS TEAMS	R^2	P (α=0.05)
Background/ Total high-level skills	0.73	< 0.001
Organization/ Total high-level skills	0.65	< 0.001
Project Management/ Total high-level skills	0.63	< 0.001
References/ Total high-level skills	0.59	< 0.001
Abstract/ Total high-level skills	0.54	< 0.001
Background/Organization	0.45	< 0.001
Project Management/Organization	0.30	< 0.001
Project Management/References	0.29	< 0.001

The results for the second paper in Capstone 2 are shown in Table 11. Background was once again more highly correlated with the total number of high-level skills. Background was correlated with organization ability and with the ability to describe the testing and analysis needed to validate their design.

Table 11: Pearson's R values for Capstone 2 Report 1, Individual Teams

PAIRED FACTORS for INDIVIDUAL TEAMS	R^2	P (α=0.05)
Background/ Total high-level skills	0.75	< 0.001
Organization/Total high-level skills	0.66	< 0.001
Testing & Analysis/Total high-level skills	0.65	< 0.001
References/Total high-level skills	0.61	< 0.001
Abstract/Total high-level skills	0.54	< 0.001
Background/Organization	0.50	< 0.001
Testing & Analysis/Background	0.37	< 0.001

Discussion & Conclusions

Comparing and contrasting the capstone progress of different majors as evidenced in their writing skills serves to highlight areas of strength to be reinforced as well as opportunities for improvement to guide our engineers. This is true, not only for the capstone experience, but for any complex project they may encounter in their future careers. We have outlined the lessons from this work to assist others in recognizing the value of the writing component in this regard.

Background Research. Positive correlations for project outcomes and the ability to write literature reviews based on quality sources are seen frequently. This skill is not only the key to many of the desired high-level behaviors, but it is also a skill that seems to vary a great deal between the two disciplines. ME teams consistently performed better in the background research skills. This may be because the relevant literature may seem more apparent to the ME students.

It is natural for students building physical prototypes to search patents, textbooks which provide thermofluids and other related equations, and technical reports from sponsors such as NASA. IE students seem less inclined to seek out literature sources or cite textbook sources that they may have seen in their classes, or through their discipline-specific proceedings and journal.

Another factor is that nature of IE projects necessitates more in-depth background research into similar companies, operations, and processes in the form of outlining best practices and conducting competitive analyses. What was formerly termed “Literature Search” has now been expanded to be called “Background Search” to include aspects of researching treatises *and* conducting analyses of similar practices in industry. This type of dual-approach preliminary research is trending toward more informed project foundations in industrial engineering capstone. Further analyses will establish these outcomes in the future.

Organization and Project Management. While it has not been statistically established, an ongoing observation of the capstone coordinators has been that once the IE teams establish their foundational project plan and advanced organizational structure, there is reluctance to alter from that carefully planned path. This is evident in the results from Capstone 2 Report 1, which generally show lower outcomes for the IE teams. IE teams seem reluctant to alter their Capstone 1 reports based on feedback due to this fixation on their existing written solution. It is now incumbent upon capstone coordinators, writing associates, and advisors to encourage and expect that there will be changes and deviations from the initial path and plan. Being agile and adaptable can lead to high levels of success.[13] Capstone leadership must work to foster this.

Testing and Analysis. As reported above, the testing/analysis scores were higher overall for the ME teams, which is more on par with the ME culture of having a physical item to test and revise. There is more to be done to continue encouraging IEs to treat their solutions as entities to be analyzed, tested, revised and reviewed. This ,sometimes requires more abstract thinking when a process is being revised as opposed to an object or product.

Variability across Factors. As previously noted, one of the prevailing findings was that the industrial engineering team outcomes tended to be much more variable than those of the mechanical engineers. Some IE teams achieved highly, while others were found to be performing on the lower end of the spectrum on some of the critical measures. This is less so for the ME cohorts. This finding encourages the IE leadership to involve the faculty advisors as well as the coordinator in support of the writing instructor to emphasize the necessary and contributory components of the design and documentation process. It is important to note that in the end, IE students do achieve successful solutions as evidenced by prototype scores. Disciplines that emphasize processes and controls, such as IE, may need additional support early in the curriculum to balance the need for strict protocols with the creative demands of design work.

This research has reinforced that there are always opportunities to improve not only the projects and outcomes in Capstone Design, but also the process that informs and leads to the respective solutions. An in-depth analysis of the critical writing elements across two majors has revealed areas of predictable success as well as opportunities to be proactive in guiding all steps of the design process.

Future work. The results of this work provide several ideas for programmatic changes as well as research ideas. Enlisting an engineering librarian to aid the IE students in learning their way around the literature space for industrial engineering would be a good first step. This could be incorporated into classes before Capstone as well as during the Capstone course. Although there has been historically a separation between the MEs and IEs, unless on a joint project, activities that have teams work across the disciplines could be an advantage for both. An exercise in peer evaluation of another team's literature review from the other discipline could draw on the relative strengths of the MEs in this area to help the IE students advance.

One aspect of the reports that was not specifically studied in the current research was that of graphical presentation. IE students learn a great deal about visualization in terms of facilities layout, string diagrams, and other related visual presentation of data. It would be interesting to determine the relative strengths and weaknesses of each discipline in this area, as visual presentation of data is a key skill for engineers. Additional research into the length of idea fixation for each discipline also seems warranted. By knowing at what point ideas become fixed for each group, appropriate interventions to prevent premature fixation could be applied, and teams could receive guidance to catalyze further innovations.

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