University of Nevada, Reno

Multifaceted Learning Objective Assessment in a Mechanical Engineering Capstone Design Course

A thesis submitted in partial fulfillment of the

requirements for the degree of Master of Science in

Mechanical Engineering

by

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December, 2016

THE GRADUATE SCHOOL

We recommend that the thesis
prepared under our supervision by

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Entitled

Multifaceted Learning Objective Assessment In A Mechanical Engineering Capstone Design Course

be accepted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

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ABSTRACT

This thesis details multi method research approaches that have been used to study student learning objective instruction and assessment in the mechanical engineering (ME) capstone course at the University of Nevada, Reno (UNR). A primary focus of the research is to evaluate the pilot implementation of a Writing Fellows (WF) program in the ME capstone course, which has been assessed using a variety of techniques. The assessment generally indicates positive results. In particular, students favor the continuation of the program and find it more helpful than group consultations within the University Writing Center (UWC) alone. Self-assessment by the students indicates higher confidence in their communication skills, while preliminary analysis suggests that the writing fellow improved the scores of graded assignments by approximately one-third of a letter grade overall. Assessment efforts also highlight the need for deeper interaction between the WF and engineering faculty. A secondary focus of this research presents a methodology that has been developed and used to analyze how the Accreditation Board for Engineering and Technology's (ABET's) current Criterion 3 Student Outcomes (SOs) have been assessed in UNR's ME capstone class over several academic years. The methodology generally finds levels of ABET SO assessment in agreement with departmental and industry-held expectations for capstone courses at large. Finally, an analysis of student grades in the capstone course finds significant differences across semesters and identifies several potential causes.

DEDICATION

This thesis is dedicated to my wife and my daughter, who both push me to pursue great things each and every day. I couldn't have done it without you incredible women.

ACKNOWLEDGMENTS

I would like to thank Dr. Emil Geiger, Dr. Eric Wang, and Dr. Adam Kirn of my graduate advisory committee for their support, guidance, and expertise as engineering educators. Portions of this material is based upon work supported by the National Aeronautics and Space Administration under a Space Grant award to Nevada NNX10AN23H issued through the Nevada Space Grant Mission Directorate.

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1 INTRODUCTION & BACKGROUND

1.1 Thesis Overview

Undergraduate engineering capstone courses are designed to offer students a chance to synthesize and apply knowledge gained during an entire academic career while working through a hands-on design project. Given the breadth of topics any single design project might cover and capstone's nature as "a critical link in engineering education [for young engineers] between academic and professional experiences," [1] these courses offer a unique opportunity for educators to assess a variety of learning outcome objectives prior to degree completion. This work describes multi method research approaches that have been used to study student learning objective assessment in engineering capstone courses, through evaluation of the mechanical engineering (ME) capstone courses at the University of Nevada, Reno (UNR). A primary focus of this research evaluates the implementation and assessment of an alternative writing skill development program, the "Writing Fellow" program, within the ME capstone course. The remaining work presents an applied methodology that has been used to analyze how current Criterion 3 Student Outcomes (SOs) mandated by the Accreditation Board for Engineering and Technology (ABET) are assessed in UNR's ME capstone class. A discussion of key results and observations encountered, recommendations for other researchers, and implications of this research is included.

1.2 UNR's ME Capstone Course Structure and History

The ME capstone courses at UNR utilize a familiar overarching course structure in which students typically work in teams on a year-long design project that culminates in a spring exposition where the teams demonstrate their prototypes. The courses were recently changed to a two-semester sequence (ME451 and ME452) starting in the fall semester of 2011. To support engineering communication as one of the primary educational objectives, the students are typically required to report on their projects in a variety of modes:

1. Tasks – Throughout the fall semester, students submit 2-3 page written reports every 2-3 weeks on their progress. These reports focus on the early and middle stages of the design process.
2. Design Reports – At the end of the fall semester, students build on the information previously reported in the Tasks in a "Preliminary Design Report." This report is revised in February and again in May to capture their progress. These revisions are called the "Intermediate Design Report" and "Final Design Report," respectively.
3. Other communication assignments – Throughout the year, students build a website for their project. In the spring semester, students give oral presentations on their project and write a business plan. Finally, students prepare a poster for the spring exposition to accompany the live demonstration of their projects.

The capstone course also fulfills and assesses key ME undergraduate curriculum objectives. The course's objectives are aligned with both departmental

and ABET accreditation requirements, and include developing student narrative structure and communication skills as major components.

Due to dramatic increases in enrollment as high as 34% year-over-year, UNR's ME capstone course instruction team has been forced to adopt multiple curriculum development, instruction, and assessment methods since the 2014-15 academic year to present content and assess students on learning objective achievement. Such activities include utilizing a "flipped classroom" approach in which video lectures are provided online (rather than verbally during class meeting hours) and allows for course time to be used for discussion, problem solving, and peer review. To assist with the flipped classroom curriculum design, the course instruction team implemented a rigid structure requiring students to view the online lecture content, prepare materials for their in-class meetings, and organize and attend team meetings. Numerous external support systems, including the University Writing Center (UWC), have been used by ME capstone faculty with the objective of enhancing student writing skill development. The ME capstone course has also utilized team mentors since the 2014-15 academic year who both review normally assigned tasks and offer technical guidance through the design process. The mentors are typically other engineering faculty, qualified graduate students and alumni, or local practicing engineers.

The ME capstone course recently underwent a major logistical change with the resignation and replacement of the primary instructor between the fall 2015 and spring 2016 semesters. While this change has contributed to a shift in assessment practices (rubrics/grading) and detailed course curriculum

(assignments), the overarching emphasis continues to be rooted in presenting and assessing common key design concepts – such as concept generation, specification development, and prototype test planning – through development of a successful hands-on design project.

1.3 Learning Objective Assessment in Capstone Courses

Given their nature as largely the final design courses for engineering undergraduates, capstone courses have historically struggled with their own unique set of assessment issues that impact numerous stakeholders – including curriculum developers, faculty members, and students alike [2]. Coupled with this, engineering capstone instructors continually find difficulty in engaging students to actively participate in writing skill development [3]. While the vast majority of undergraduate engineering courses typically focus primarily on teaching students the technical aspects of engineering, capstone courses offer a unique opportunity for instructors to further develop and assess skills not typically associated with engineering – most notably effective technical writing skills – in addition to evaluating the effectiveness of prior technical courses within the context of an applied design project. Although these assessment advantages may be present, many capstone students remain averse to advancing non-engineering skills and view them as not necessary for their professional endeavors. To this end, ME capstone faculty at UNR have leveraged the UWC, Writing Fellows (WFs), and industry mentors including ME faculty to provide external support facilitating writing skill development for ME capstone students. A primary focus of this thesis is to

describe the implementation and assessment of a WF program in UNR's ME capstone course.

Other issues of assessment in capstone are related to program accreditation. To maintain accredited status and a reputable stance amongst those in industry, collegiate engineering programs are typically certified to a specific set of academic standards by ABET [4]. ABET ensures accredited engineering programs can fulfill specific requirements related to administration (General Criterion 1), educational objectives (General Criterion 2), and student outcomes (General Criterion 3) of engineering programs, among others [2]. As with many academic benchmarks, achievement of 11 specific student outcomes (SOs, also ABET a-k outcomes) is demonstrated through assessment of student work in various classes throughout a program's entirety [5], [6]. Several engineering education researchers have emphasized curriculum assessment as a tool for ABET SO assessment [7]. While SO assessment objectives are typically established for each course at the program-level, currently no quantitative methodology is in use by UNR's ME department to determine relative levels of SO assessment in undergraduate ME classes – including the capstone course sequence. Coupled with this, no analysis has been performed to determine key SO (KSO) assessment emphasis, benchmarks for relative student performance across capstone assignments, and the relationship between KSO assessment emphasis and student academic performance. A second goal of this thesis is to describe development and implementation results of using a quantitative

methodology to evaluate levels of SO assessment and corresponding levels of student academic performance in the ME capstone course.

1.4 Research Questions

To address these issues related to assessment in engineering capstone, the following research questions are proposed.

RQ1. What effect does implementation of the WF program in the ME capstone course at UNR have on student performance for major writing assignments?

RQ2. Considering course materials and SO assessment in the ME capstone class, how is SO assessment emphasis distributed for major assignments and final course grades, and how has the emphasis evolved with changes to the capstone course design?

RQ3. How have student grades for major assignments and the overall ME capstone course varied over the past three years?

The research framework, data analysis processes, and results needed to answer to these questions and understand their implications are presented in the chapters that follow.

2 WRITING FELLOW IMPLEMENTATION & ASSESSMENT

2.1 Background & Motivation

The ability to communicate effectively is a critical skill for engineers, and there are many reports documenting the efforts to increase the focus on communication within engineering programs [1–6]. Capstone design courses are a natural opportunity to concentrate on communication, within the context of an open design problem, due to the similarities between the writing and the design processes [7-8]. In both, an iterative approach must be pursued. As new information comes to the fore, previous work must be revisited to ensure harmony throughout the project. Individual voices must be reconciled and made one. Furthermore, there are few instances where design or communication has a single "right" answer.

Different approaches have been pursued to support the students in their writing and communication within capstone courses. At one end of the spectrum, engineering faculty have partnered with writing faculty to divide the instructional duties [9 – 13]. In these cases, engineering faculty typically focus on instructing the students on technical aspects of the capstone course while the writing faculty, who may come from the English department or even be an expert in technical communication, focus on communication aspects. While this approach has been effective, it is resource-intensive and requires "buy-in" from many stakeholders across the university. At the other end of the spectrum, engineering faculty may simply rely on existing resources such as the University Writing Center (UWC) to support the educational objectives related to communication. While this approach

leverages resources that are in place, the UWC is challenged to provide specialized instruction for the engineering students [14]. Therefore, this option can be less effective.

This chapter will focus on the implementation and assessment of a Writing Fellows (WF) program in the ME capstone design course at UNR. The WF program, a middle ground approach, uses the existing infrastructure provided by the UWC and attaches a single writing consultant, i.e. a WF, to the capstone course. This approach retains some elements of a dedicated instructor while requiring fewer resources than team-teaching. This chapter provides an overview of the WF program, reports initial assessment results, and discusses the program's successes and continuing challenges.

2.2 Writing Fellow Program History

The first WF program was founded at Brown University in 1982 [15, 16]. In the 30+ years since, WF programs have diversified in their focuses: wide-ranging departments and disciplines, courses with high failure rates, writing-intensive courses, and specific disciplinary writing [16]. Fellows can work to support student writers individually, support/inform faculty, and most often some combination of the two [17]. WF programs share characteristics with peer review, faculty conferencing, writing centers, supplemental instruction, teaching assistants (TAs), and writing studio courses; all of these characteristics can lead to challenges in WF implementation. While these various roles can make duties of WFs less clearly defined, they more importantly testify to the adaptability of WFs to an array of educational demands and contexts. Still, their central purpose remains stable:

providing specialized support for discipline-based writing and communication skill development.

UNR's WF program has been operating since the spring semester of 2013, exhibiting generally positive interactions between WFs and students / faculty, strengthening of cross-discipline collaborative efforts related to communication skill development, and measurably improving student writing as this chapter will further illustrate. The WF program was born out of a successful UWC that takes pride in adapting to demands and interests across the curricula. The WFs have been selected largely by the faculty members whose students the fellow will support. WFs are generally upperclassmen undergraduate students, as funding for the program is not sufficient to support post-graduate TA student salaries (in fact, a single WFs salary per semester is equal to less than half of a graduate TA's monthly salary at UNR). The fellows operate based on the needs and interests of the target faculty, students, courses, and programs. UNR has had success in matching abilities, resources, and fellows through implementation of the WF program. Obviously, the primary benefit of a WF program is better student writing. However, two other regular benefits are also worthy of note: ongoing professional development (as service providers or receivers) for all involved and comparatively low costs.

The use of WFs also accomplishes important programmatic goals. While the imposition of writing expectations from outside departments can often provoke resistance, WFs provide resources that disciplinary faculty can deploy in ways that make sense for their courses, students, and assignments [18]. More importantly,

for the programs making use of fellows, the support is knowledgeable and resource-efficient. There are some risks inherent in WF programs as well. The seeming ambiguity of WF responsibilities can leave the fellows vulnerable to interactions with faculty members following professor-student hierarchy rather than between co-instructors [15]. By extension, the students with whom they work can then be at some risk of misguidance, which not only does not serve the intended purposes of a WF program but also complicates them. Direct, open, and honest communication between the faculty, fellows, and directors of programs offering fellows is essential [19]. Regardless of other concerns these communications must always be held in confidence, and UNR has consistently found these conditions with WF program participants.

2.3 Writing Fellow Integration in Capstone

The WF and UWC have helped the ME capstone instructional team facilitate student communication skill development. Pilot implementation of the WF within the ME capstone course occurred during the spring 2013 semester, and efforts have been made to continue its deployment each subsequent semester. At UNR, WFs work much more independently and directly with faculty than traditional writing center staff; as such, their formal training focused on mindful and professional activities between students and faculty, working to understand and represent each accurately to the other. Beyond this formal training, WFs participated in ongoing training after the semester began, focusing on dealing with questions, issues, and relationships that came up as the semester continued. This was especially important since each WF worked with a different faculty member

and course. Training generally took 6-8 weeks, utilizing training materials available online, received from the faculty member, and developed by senior UWC staff. As a whole, WFs were trained to support faculty writing goals and develop student abilities toward specific writing tasks, all within the context of UWC policies and best practices.

The “ideal” WF for the ME capstone course would be an upperclassmen / post-graduate ME student with demonstrated writing proficiency who was not enrolled in the course sequence. In many cases, finding a qualified student who exhibited these traits was not possible due to the nature of the WF recruiting process. For the ME capstone class WFs were either recruited by the primary engineering instructor and trained by the UWC or selected from the existing pool of UWC writing consultants. In all cases the WF was an undergraduate engineering student, ranging in class standing from sophomore to junior. Several of the WFs had backgrounds in technical writing as members of various academic research labs at UNR in addition to their undergraduate coursework experience. WFs met directly with the capstone faculty to understand the overarching communication skill development objectives of the course. The WF would also meet with the ME capstone faculty to discuss the specific goals and expectations for each assignment, including reviewing elements of the grading rubric as needed.

The primary responsibility of the WF was to support both the student teams and capstone faculty by providing feedback on drafts of assignments ahead of submission. Particular attention was given by the WF to elicit adaptable student writing styles and techniques, allowing students to present technical content with

a clear and concise narrative. In essence, the WF was a specialized writing consultant attached to the capstone class. The student teams were required to provide a draft of their assignment to the WF at least 24 hours before their meeting. True to the nature of the WF program, the fellows would respond to both higher-order and lower-order concerns as a peer reviewer [20 – 23]. While the WF mostly supported the student teams with their written work, he/she could provide feedback on any of the communication assignments including oral presentations, posters, and the team website. WFs did not revise student work directly but, rather, facilitated student writing practice and skill development. Functionally, the WF was somewhat insulated from the day-to-day aspects of the class, which allowed a unique perspective on the documents under review. After each meeting the WF would write a short report documenting attendance and outcomes. The logistics of scheduling the meetings and reporting were handled through the UWC web interface. The WF was prohibited from grading. After each assignment, the WF would meet with the engineering faculty to debrief and discuss how the students responded to the assignment.

The WF program provided for approximately 50 hours of direct support each semester. Enrollments in the ME capstone sequence were 89, 69, 103, and 127 students in the 2012-13, 2013-14, 2014-15, and 2015-16 academic years, respectively. Teams consisted of 5 members with 13 – 27 teams per semester, thus the WF could spend a maximum of approximately 3 hours with each team. The exact requirements of when the student teams would meet with the WF, for how long, and for which assignments would vary based on the number and type

of assignments in a given semester. Generally speaking, students were required to schedule half-hour meetings for 2-3 of the smaller assignments of their choosing and a mandatory one-hour meeting for the larger reports. For the larger reports, rough drafts would be submitted to the WF approximately 2 weeks before the due date, giving the WF sufficient time to meet with all of the groups.

2.4 Assessment Instrument Development

The observations and data reported here related to RQ1 cover the Fall 2012 (F12), Spring 2013 (S13), Fall 2013 (F13), Spring 2014 (S14), and Fall 2014 (F14) semesters of the ME capstone course. A summary of reporting semesters and mode of supplemental writing guidance is given in Table 2.1. As previously mentioned, the WF program was initiated in S13. As such there was no WF for F12, and instead students were required to meet in groups with regular UWC staff following the frequency and meeting requirements of the WF outlined above. F12 data was collected at the beginning of the S13 semester as part of a retrospective review of course achievements. For the capstone course, a single WF was used during the S13 semester. A second WF started in the F13 semester but resigned in the middle of the semester. Another engineering student, who was already a writing consultant in the UWC, was able to assume the WF role for the remainder of the F13 semester and on through S14. Unfortunately, a WF could not be recruited and trained from either the UWC staff or the greater undergraduate engineering student body for the F14 semester. For F14, writing feedback was accomplished with a combination of peer reviews, mentor reviews, and UWC consultations.

Table 2.1. Modes of supplemental writing guidance within the ME capstone course, Fall 2012 through Fall 2014.

Semester	Supplemental writing guidance mode(s)
F12	UWC
S13	UWC + WF
F13	UWC + WF
S14	UWC + WF
F14	UWC + team mentors

The current assessment of the WF was accomplished in four ways involving the three key stakeholders in the ME capstone's WF implementation: students, faculty, and WFs themselves [19]. First, anonymous 'communication surveys' were deployed to the students via online instructional tools (Blackboard). Second, the engineering faculty informally interviewed the student teams. Third, since the student teams were able to choose which assignments they would bring to the WF meeting, the engineering faculty and graduate TA graded the assignments without knowing which submissions had input from the WF (referred to as blind grading). Finally, the WFs were asked to provide short reflective essays on their impressions and observations.

A summary of WF-related communication survey content is given in Table 2.2. The communication survey (CS) was aimed at gathering both quantitative and qualitative student opinions about the WF, personal communication skill development, WF and UWC interactions, and performance of capstone faculty in implementing capstone communication curriculum at the end of each semester.

Table 2.2. Communication survey question descriptions and mode of student response.

Question Type	Question Description	Response Mode
Personal Writing / Communication Skills	Q1: Before taking ME capstone, how would you rate your writing / communication skills?	1–10 rating
	Q2: After taking ME capstone, how would you rate your writing / communication skills?	1–10 rating
	Q3: What were the three top reasons that contributed to your skill improvement (if any)? What else would have helped you improve your skills further?	Free response
WF Opinions	Q4: Was your required consultation with the WF / UWC / mentor helpful? Why or why not? Did you meet in addition to your required meetings?	Free response
	Q5: Thinking about your interactions with the UWC and the WF, please rate the following: "Working with the WF was ____ than working with the UWC."	Multiple choice ranging from "much more helpful" to "much less helpful"
	Q6: What did the WF/mentor do that was the most and least helpful to the improvement in your communication skills (if any)? If the ME capstone class continues to use a WF/mentor in the future, how might we improve his or her effectiveness?	Free response
	Q7: Should the ME capstone class continue to use a WF/mentor in the future?	Multiple choice ranging from "Strongly Agree" to "Strongly Disagree"
	Q8: With regard to any changes made to the documents you brought to the required consultation with the WF, select the statement you most strongly agree with:	Multiple choice
	(A) The WF helped me find issues in my team's writing and offered suggestions to overcome them in the future.	
	(B) The WF helped mostly with low-level writing issues and did not offer suggestions to improve my team's overall writing ability.	
	(C) The WF made the changes to my team's writing without offering suggestions for future improvement.	

The communication survey was revised each semester prior to deployment to further refine their scope of inquiry and evaluate any subsequent changes to the WF's role within the capstone course. This is partially due to the continual evolution of UNR's WF program. Student feedback has helped to improve both the WF program and associated communication survey questions to address new areas of insights and deficiencies. Major revisions included adding questions to clarify student opinions about the effectiveness of the WF relative to capstone

faculty, and evaluate performance of WFs in providing high-level skill development rather than performing basic spell checking and grammatical proofreading of student work alone. Results from these questions assist in characterizing actual student communication skill improvement facilitated by the WF when coupled with blind grading results. Minor CS revisions generally consisted of streamlining language themes for questions and removing potential response bias induced by question framing. While revisions were necessary to enhance the survey's robustness, common themes are present that allow for analysis and comparison across semesters and as a pooled UNR ME capstone student grouping. The survey's final version is shown in Table 2.2.

2.5 Analysis, Results, and Discussion

Although a variety of assessment methods were employed, the communication survey data was the most insightful. Overall CS response rates were 75%, 50%, 41%, 71%, and 55% for the F12, S13, F13, S14, and F14 semesters respectively. An overview of individual communication survey response frequencies is given in Table 2.3.

Table 2.3. Communication survey individual response frequencies given by question and responding semesters.

Question	Semesters Responding	Number of Individual Responses
Q1	F12, S13, F13, S14	190
Q2	F12, S13, F13, S14	189
Q3	F12, S13, F13, S14, F14	188
Q4	F12, S13, F13, S14, F14	233
Q5	S13, S14	91
Q6	S13, S14	84
Q7	S13, S14, F14	140
Q8	S14	49

The first two communication survey questions asked the students to evaluate their own writing or communication skills on a scale of 1-10 before (Q1) and after (Q2) taking the course. The results of Q1 and Q2 analysis indicate that ~20% more students ranked themselves at 7 or higher after taking the course as compared to their ranking before the course (Fig. 2.1). Interestingly, the survey responses for each semester were remarkably similar and the impact, if any, of the WF over other modes of writing support could not be discerned. An analysis to determine significance of differences in Q1 and Q2 responses (or, more broadly, quantitative student assessment of general communication skill improvements facilitated by the capstone course) between semesters that utilized a WF and those without found that no statistically significant difference was observed with a minimum P-value of 0.068 (t-Test for independent samples of differences in average Q2 – Q1 values, selected significance level $\alpha = 0.05$). This result along with general trends in qualitative student responses may indicate that further revisions to the communication survey may be needed to provide a more robust student assessment of WF effectiveness. Special attention will be given during future assessment development to evaluate the face validity of communication survey assessment instruments to ensure their questions are capable of capturing desired information without restricting the breadth of student responses or causing bias in results (similar to [24]).

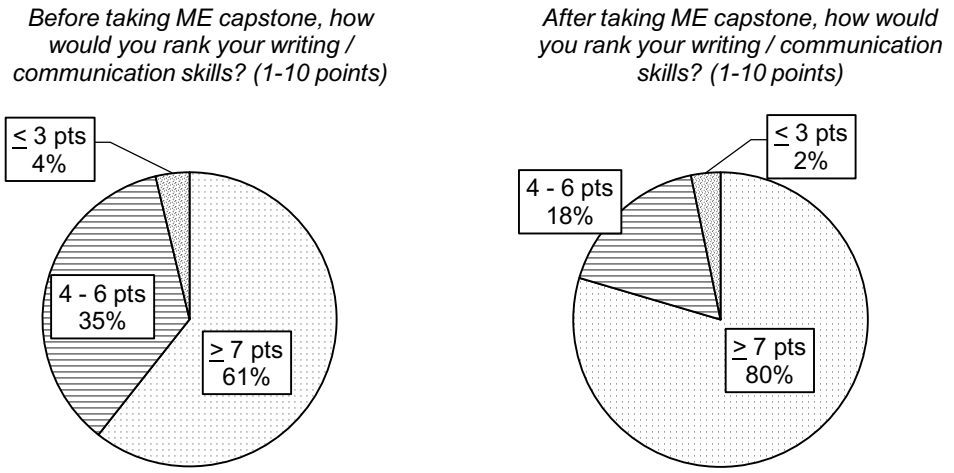

Figure 2.1. Pie graphs of cumulative Q1 / Q2 student response distributions.

When looking at the questions that were specifically about the WF, the responses were much more favorable. When asked if the ME capstone class should continue to use a WF (Q7), 69% of responders either agreed or strongly agreed while 18% disagreed or strongly disagreed. Furthermore, 77% of respondents stated that the WF was either much more helpful or somewhat more helpful than the UWC, as opposed to 7% who felt that the WF was somewhat less helpful or much less helpful (Q5). These results are encouraging and demonstrate that the students appreciated the role of the WF within the course. When asked about the nature of their interactions with the WF (Q8), 73% of responders felt the WF gave high-level insight into common writing mistakes and offered suggestions for future improvement while 27% felt the WF only offered help to correct low-level writing issues without offering suggestions to improve the student team's writing abilities; no respondents felt that the WF simply performed necessary document revisions without offering suggestions for writing skill development. Most student answers to free response questions had trends indicating a self-reported

improvement in personal writing quality. Even when they did not, their responses demonstrated increased awareness of the quality of their writing.

Several free response questions (Q3 and Q4) asked how capstone curriculum and WF meetings helped students with their writing (if at all), as well as inviting suggestions for improvement in the WF's effectiveness (Q6). When comparing results between semesters utilizing UWC resources only and those with a dedicated WF, 88% of respondents view their interactions with the WF as helpful while 73% of respondents view UWC interactions as helpful for communication skill development (Q4). Two major positive themes emerged in student responses about the WF meetings: "I[t] was good to have an outside perspective review papers," and "[the WF] understood the technical elements of the papers." The most common negative comment was some version of, "No, ...[the WF] would more just check for grammatical errors." On the other hand, some students did value the focus on grammar. Whether positive or negative, the focus on grammar was surprising as the WFs were instructed to focus on higher-order concerns (focus, organization, development, etc.) first, followed by lower-order concerns (sentence and word-level).

Although many students found their meetings with the WF to be beneficial, suggestions for how the WF's role might be improved overwhelmingly sought deeper interaction between the Capstone instruction team and the WF to create clear-cut writing expectations for each assignment. This demonstrates a potential limitation of the WFs role as a teaching assistant who carries no grading power, as incongruities in expectations of student performance between capstone faculty

and WFs may not be easily identified until multiple teams receive unexpectedly low task scores on a frequent basis after having a favorable assessment by the WF. Another suggestion involved having the WF give 1-2 lectures on common issues that occur with technical writing. Some students thought that the WF should have been a senior student or even graduate student due to the level of writing experience associated with the capstone class. Student opinions about WF qualifications are in line with those of the capstone faculty, and demonstrate a limitation of the program's funding and resultant man-hour support capacities. Despite being generally well received, an overwhelming majority of students (~90%) did not meet with the WF beyond those required by the course (Q4). Many students indicated that they would have preferred meeting with the WF more but were precluded by scheduling issues, both with the WF and within their respective teams. These results indicate that future WF implementation may require additional WFs to meet the needs of the growing capstone student body.

While no WF was utilized in the ME capstone course for the F14 semester, CS results were obtained focusing on the roles of student team mentors to serve as a means for comparison with CS results for semesters using WFs. F14 CS questions about which aspect of the course contributed the most to personal student communication skill improvement and what may have helped students improve further generally indicated similar responses to those of semesters with WFs. Common positive themes contributing to student development include the use of mentors to facilitate development of professional technical writing skills, peer review of assignments prior to submission, practicing group work on

engineering projects, and the available UWC resources. Common negative themes that did not aide communication skill development include perceived incongruities in communication skill expectations between UNR's dedicated engineering communications course and the ME capstone course and a lack of feedback on communication skills within graded task rubrics; these themes offer opportunities for course improvement by the capstone faculty and are not within the purview of WF duties within the capstone course.

Similar to the UWC program, many respondents (74%) found meeting with their mentor to be beneficial. Unlike WF survey results, respondents focused on the helpfulness of the mentors' professional engineering experience to help evaluate and guide project design choices, with fewer respondents noting communication skill development aided by the mentor. Additionally, 40% of respondents indicated they met with their team's mentor beyond requirements of the course, and 74% of respondents strongly agreed or agreed that the mentor program should be continued, but investigation into the statistical significance of response differences between semesters utilizing team mentors and those with WFs could not be made due to the question's phrasing. Many suggested areas for improvement in the mentor program were also similar to those made for the WF program, including adding to the pool of mentors and increasing their availability to meet with teams, and for the capstone instruction team to clarify expectations of the mentors to improve interactions. The similarities between the mentor and WF communication survey results indicate that a happy medium may be to leverage both resources simultaneously, with mentors working to develop feasible

technical aspects of student team projects and tasks, and WFs focusing on broadening higher-level student communication skills and writing style adaptability within the context of the ME capstone course.

Informal discussions between engineering faculty and student teams covered writing and communication within the context of the capstone class, including the implementation of the WF. The informal discussions supported the same conclusions gathered from the surveys regarding the WF. Additionally, students stated that the group-written reports helped ensure that the team "was on the same page" and exposed individual assumptions about the design project. In this regard, the written reports were more than just a reporting mechanism and actually contributed to the design process.

Tracking assignments that received input from the WF for the blind grading assessment only occurred during the F13 semester. A summary of average Task scores for assignments with ('WF Task score average') and without ('Group Task score average') WF input are given in Table 2.4 along with which task(s) had input from the WF. Due to a clerical error the meeting and Task summary for one team has not been accounted for in the table. There was a total of 70 Tasks submitted (5 Tasks for 14 teams), of which 15 received input from the WF. The impact of the WF was evaluated in 3 ways: a) all tasks collectively, b) each task individually for all teams, and c) each team individually for all tasks. The results of each of these calculations showed that the input of the WF helped the students by slightly better than 1/3 of a letter grade (i.e. C to C+ or B- to B, etc.). Interestingly, six of the

teams received their best task scores with input from the WF. Furthermore, no teams performed worse after meeting with the WF.

Table 2.4: Blind grading results for Fall 2013 semester. Note a 15-point grading scale is used to assign task letter grades (i.e. – 'A' range = 85-100%, 'B' range = 70-84%, etc.)

Team	Group Task score average	WF Task score average	Group – WF Task score average delta	Tasks with input from WF
A	70%	80%	+10%	5, 6
B	72%	78%	+6%	2, 3, 6
C	53%	56%	+2%	3, 4, 6
D	72%	81%	+9%	3, 4, 6
E	46%	47%	+1%	3, 4, 6
F	69%	74%	+5%	2, 5, 6
G	65%	71%	+6%	2, 6
H	74%	83%	+8%	3, 5, 6
J	61%	70%	+9%	2, 6
K	61%	83%	+22%	4, 5, 6
L	65%	73%	+8%	2, 3, 6
M	55%	63%	+8%	2, 6
N	64%	69%	+5%	4, 6
Column Average	64%	71%	+8%	N/A
Column Std. Dev.	8%	11%	5%	N/A

A paired t-Test was carried out to determine significance of the observed differences between Group Task score average and WF Task score average grades, which found the difference to be statistically significant (P-value = 0.00012, selected significance level α = 0.05). While the general trends of blind grading results are encouraging, the small sample size and utilization of two different WFs in the F13 semester must be remembered during interpretation. Additionally, variations in grading between the TA and faculty and changes in rubrics from task to task have not been considered. It should also be noted that the teams were allowed to resubmit one task for a re-grade. Many student teams met with the WF to review the task, and subsequently re-graded submissions were improved by approximately one and a half (1.5) letter grades. This lends support to the

student's comments that the WF should work more closely with capstone faculty, as a markedly greater improvement in task grades was observed when the teams interacted with both the professor and WF as compared to the WF alone. In particular, the expectations of the faculty must be made clearer to the WF to support their roles [25].

The reflective essays provided by the three WFs provided valuable insight into strengths and weaknesses of their role with the ME capstone course. All three WFs expressed that students seemed to appreciate the extra set of eyes reviewing their work; this was helpful in improving the cohesion of tasks and design reports authored by student teams. The WFs also agreed that the group discussions in their meetings facilitated the student team's abilities to reach their own conclusions while addressing the structure and purpose of each assignment. The statement of one WF, in particular, characterized these sentiments: "Engineers tend to write papers by checking boxes, rather than examining the overall reason for creating what they are writing, and I was doing my best to get that to change." The WFs also agreed that the majority of the writing issues they encountered stemmed from this linear thought process, along with a "black-and-white" approach many students applied to their reports. The WFs identified several potential areas for improvement in the future implementation of their roles, including working further on helping students develop an adaptable writing style and setting clear assignment expectations with the course instructor. Overall, the WFs were pleased with their interactions with students and believed that the skills they tried

to elicit during their sessions would be useful to students in their professional lives beyond the capstone course.

2.7 WF Assessment Conclusions

The instructional team's observations on the WF program are provided as a final point of discussion. In particular, it is important to note that identifying and recruiting qualified and interested candidates for the WF position has proven to be challenging. The ideal candidate should be an upper classman in ME, but should not already be in the capstone course. Of course, students from other engineering disciplines or STEM majors could also be (and were) considered. Broadening the search did not lead to a suitable candidate for the F14 semester despite the efforts of the UWC and ME faculty and staff, which leads to concerns about the sustainability of the WF program in the capstone course. This was particularly unfortunate since the F14 semester had a record high enrollment of students in the ME capstone course. Moreover, funding levels for the WFs also precluded the use of graduate teaching assistants. An additional requirement, which is perhaps more challenging to fulfill, is finding a STEM candidate that is interested and passionate about improving writing and communication. In fact, of the three WFs, the student who was already a UWC writing consultant was able to provide the best feedback to the capstone teams. This is likely due to the student's experience, but also because the student had already expressed an interest in this type of work. On the other hand, the WF who resigned cited a misunderstanding of expectations. These two anecdotes suggest that the best candidate may

actually be an existing UWC writing consultant. Unfortunately, there are typically very few, if any, writing consultants from STEM fields.

Despite the challenges of identifying WFs, the instructional team did find the services of the WFs to be helpful at a qualitative level. At the same time, the instructional team had to manage the expectations of the capstone students. For example, some teams felt entitled to better grades due to their meetings with the WFs, forcing the instructional team to reiterate that the WFs should be considered similar to tutors. In other words, the student team's work had to stand on its own regardless of the input, if any, from the WFs. This resulted in some frustration for several teams. Further investigation revealed that in some of these cases, the writing of the capstone teams was too poor for the WFs to have a significant impact given the time constraints of their meetings. This reiterates a greater need for writing and communication skill development throughout the undergraduate engineering student's educational career [26].

3 ABET CRITERION 3 STUDENT OUTCOME ASSESSMENT

3.1 Background & Motivation

Put simply, ABET's 2015-2016 Criteria for Accrediting Engineering Programs are "intended to assure quality" and "foster the systematic pursuit of improvement in the quality" of engineering education [1]. The accreditation criteria serve as a set of standards against which engineering programs must be able to demonstrate acceptable performance and continuous improvement efforts when obtaining or maintaining accreditation, through use of various assessment tools and reports [2].

One particular area of interest for ABET accreditation assessment is related to Criterion 3 Student Outcomes ("SOs"), a set of 11 outcomes students must demonstrate upon graduation from the accredited engineering program [3]. Criterion 3 Student Outcomes are listed in Table 3.1 below along with their a-k identifier and coding. These outcomes are periodically assessed throughout the program in applicable courses to document levels of student achievement and identify areas for potential curriculum improvements [4].

Table 3.1. 2015 – 2016 ABET Criterion 3. Student Outcomes.

Outcome	Outcome description
(a)	An ability to apply knowledge of mathematics, science, and engineering
(b)	An ability to design and conduct experiments, as well as to analyze and interpret data
(c)	An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d)	An ability to function on multidisciplinary teams
(e)	An ability to identify, formulate, and solve engineering problems
(f)	An understanding of professional and ethical responsibility
(g)	An ability to communicate effectively
(h)	The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i)	A recognition of the need for, and an ability to engage in life-long learning
(j)	Knowledge of contemporary issues
(k)	An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Prior to ABET visits to maintain accreditation department faculty will typically review current required and elective courses for a given program of study and assigns each class a score based on whether or not it incorporates content and/or performs assessment related to each SO [5]. This is the case in UNR's ME department, and in fact several instructors have decided to share this departmental SO ranking information with their students to foster senses of transparency and ownership in obtaining applicable SOs throughout the course. Current departmental SO ranking information for UNR's ME capstone course sequence is given in Table 3.2.

Table 3.2. UNR's ME capstone courses' ABET Criterion 3. Student Outcome Scores. Note scoring: "0 – Does not address this outcome", "1 – Informally incorporates this outcome", "2 – Presents the material or performs assessment on the outcome", and "3 – Presents the material and performs assessment on the outcome".

Outcome	ME 451 (Fall)	ME 452 (Spring)
(a)	3	2
(b)	2	3
(c)	3	3
(d)	3	3
(e)	3	3
(f)	3	3
(g)	3	3
(h)	1	2
(i)	2	2
(j)	1	2
(k)	3	3

Although this scoring activity provides the department with a valuable understanding of how programmatic SO goals are achieved, it does not provide any insight into how SOs are assessed in individual courses at the assignment-level, how levels of SO assessment within a course vary with changes to curriculum, and how student academic performance is related to SO assessment within a given course. With these considerations in mind, a quantitative methodology has been developed and implemented retrospectively in UNR's ME capstone courses to fulfill these gaps in SO assessment.

3.2 Course Material SO Assessment Methods and Results

The evaluation of capstone rubrics, curriculum, and student grades relative to SO assessment requirements utilized a multi-phased approach to address RQ2 – RQ4. First, ME capstone course materials including lecture slides, major assignment rubrics, and student grades were collected for each semester between fall 2013 – spring 2016 to determine SO assessment emphasis considering all assignments that impacted final student grades. Due in part to the continuous

evolution of capstone curriculum over the three years of investigation, not all assignments were identical across fall and spring semesters. Additionally, with the significant shift in curriculum design of the spring 2016 semester due to changes in instruction faculty, a one to one comparison of spring 2016 curriculum data could not be obtained for all major assignments, but those maintained by the new instructor were included along with an assessment of final course grades.

The SO assessment scope was subsequently streamlined to focus on major tasks and assignments that were more consistent year over year and comprise roughly 50 – 70% of the final grades students obtained in the course. The major assignments used in analysis are given in Table 3.3 along with their associated identifiers and semesters of deployment.

Table 3.3. "Major Assignments" in ME Capstone used for student grade analysis. Note final grades are given in **bold**.

Assignment Identifier	Assignment Name	Semester(s) of deployment
1	Task 1 – Team Formation	Fall (F13, F14, F15)
2	Task 2 – Problem Definition	Fall (F13, F14, F15)
3	Task 3 – Concept Generation	Fall (F13, F14, F15)
4	Task 4 – Concept Selection	Fall (F13, F14, F15)
5	Task 5 – Proof of Concept Report	Fall (F13, F14, F15)
6	Fall Design Report	Fall (F13, F14, F15)
7	**Fall Course Grade**	**Fall (F13, F14, F15)**
8	Presentation 1 – Proof of Concept	Spring (S14, S15)
9	Presentation 2 – Complete Design	Spring (S14, S15, S16)
10	Presentation 3 – Business & Marketing	Spring (S14, S15)
11	Presentation 4 – Final Design	Spring (S14, S15, S16)
12	Intermediate Design Report	Spring (S14, S15)
13	Final Design Report	Spring (S14, S15)
14	Project Poster	Spring (S14, S15, S16)
15	**Spring Course Grade**	**Spring (S14, S15, S16)**

To quantify and rank SO assessment emphasis, major assignment points ("MAPs") were distributed amongst all SOs on the basis of relative emphasis for assignments 1 – 6 and 8 – 14 listed in Table 3.3. For example, on a given 100-

point assignment, 20 points may be related to assessing SO (a), 5 points may be related to assessing SO (b), and so forth. To apply a basic methodology this process, each SO was initially screened for applicability and assigned a 0 – 3 score using the following approach:

1. Determine whether or not the SO applies to the assignment and associated course materials under evaluation. If SO applies, continue to step 2 below. If SO does not apply, assign a 0 score and repeat this step with next SO.
2. Determine whether or not the assignment performs assessment of the SO. Note any instances of SO applicability but lack of assessment as potential area for improvement in assessment design and assign a 0 score.
3. If the SO is assessed in the given assignment, evaluate which of the following statements is most applicable:
    a. Statement 1: “SO is informally assessed in this assignment” – Assign a 1 score to SO.
    b. Statement 2: “SO is directly assessed in this assignment” – Assign a 2 score to SO.
    c. Statement 3: “SO is a key emphasis of this activity and is directly assessed in this assignment” – Assign a 3 score to SO.

A flowchart representation of this process is shown in Fig. 3.1.

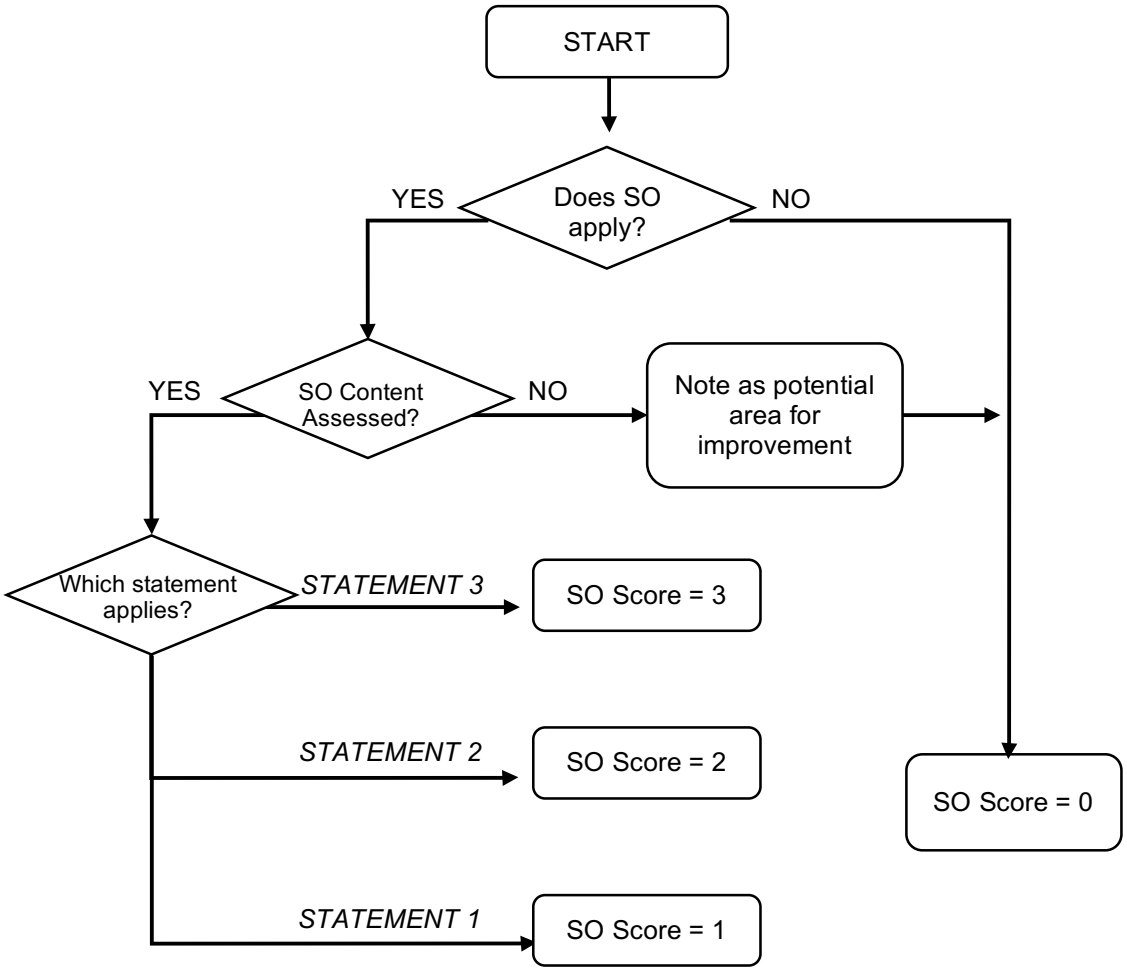

Figure 3.1. Graphical flowchart depiction of SO score assignment methodology.
Statement 1: "SO is informally assessed in this assignment";
Statement 2: "SO is directly assessed in this assignment";
Statement 3: "SO is a key emphasis of this activity and is directly assessed in this assignment".

To simplify discussion of individual SO assessment emphasis for specific assignments and semesters, the nomenclature and notation used to discuss SO assessment is as follows:

SO SCORE – The 0 – 3-point score assigned to a given SO (a) through (k) following steps 1 – 3 above for each major assignment rubric and semester under investigation. Once the SO scores were assigned and scores of 0 were removed,

assignment points were distributed among remaining SOs based on their relative 1 – 3 score following the steps outlined in Equations 1 and 2 below.

SO% – Percentage of an assignment's point value that a given SO is assessed for each semester, found using the following relation:

$$SO\% = \left(\frac{SO\ Score}{SO\ Score_{(a)} + \cdots + SO\ Score_{(k)}}\right) \times 100\% \quad \text{[Eq. 1]}$$

Finally, SO% values were summed and analyzed at the semester-level to account for variations in major assignment weightings by multiplying SO% by the amount of points possible for the assignment and dividing by the total number of points possible in all major assignments considered in a given semester:

$$FinalSO\% = \frac{\sum_{Assignments}(SO\% \times MAP)}{\sum_{Assignments} MAP} \times 100\% \quad \text{[Eq. 2]}$$

Similar to Mason et al., analysis of the data generated through the SO assessment emphasis activity comprised of identifying which SOs were assessed the most in major assignments along any notable trends in changes to SO assessment over the years under investigation [6].

Using the data analysis techniques described above we see that the primary SO assessment emphasis of UNR's ME Capstone course consistently includes SOs (a), (b), (c), (e), (g), and (k) across the three academic years under investigation (Table 3.4 and Fig. 3.2). The relative assessment emphasis of most of these KSOs have remained fairly consistent with a majority of observed SO% deltas (maximum SO% observed minus minimum SO% observed across all years under study) of less than 3% year over year. SOs (f) and (k) are the exceptions to this statement with SO% deltas of nearly 4% between academic years. It is worth

mentioning that SO (f) exhibited an increase in assessment emphasis between F13/S14 and F14/S15 but a decrease in emphasis between F14/S15 and F15/S16, while SO (k) (and several other SOs to a lesser extent) experienced the exact opposite phenomenon. The source of this shift may be attributed to one or more potential causes and is investigated further through analysis of semester- and assignment-based SO% data. Averaged FinalSO% data indicates that the six KSOs assessed in major assignments of UNR's ME Capstone course over the three academic years under study are (in order of decreasing emphasis): (a), (e), (k), (c), (g), and (b). The FinalSO% data also demonstrates SOs assessed the least in ME capstone over the same three-year period include (f), (h), and (i).

Table 3.4. Academic year FinalSO% distributions for major ME capstone assignments, excluding final course grades. Note FinalSO% values 10% or greater are shown in **bold**.

ABET SO	Fall 2013 – Spring 2014	Fall 2014 – Spring 2015	Fall 2015 – Spring 2016	Average SO %	Max – Min Delta
(a)	**11.5%**	**12.1%**	**12.0%**	**11.9%**	0.6%
(b)	**11.6%**	**10.6%**	**10.6%**	**10.9%**	1.0%
(c)	**11.1%**	**10.6%**	**12.4%**	**11.4%**	1.8%
(d)	**10.5%**	7.8%	8.8%	9.1%	2.7%
(e)	**12.1%**	**11.2%**	**12.0%**	**11.8%**	0.9%
(f)	3.9%	6.9%	3.4%	4.7%	3.5%
(g)	**13.0%**	**10.5%**	**10.7%**	**11.4%**	2.5%
(h)	4.5%	7.0%	6.1%	5.9%	2.6%
(i)	4.4%	6.4%	4.7%	5.2%	2.0%
(j)	5.4%	6.6%	6.1%	6.0%	1.2%
(k)	**11.9%**	**10.2%**	**13.2%**	**11.8%**	3.0%

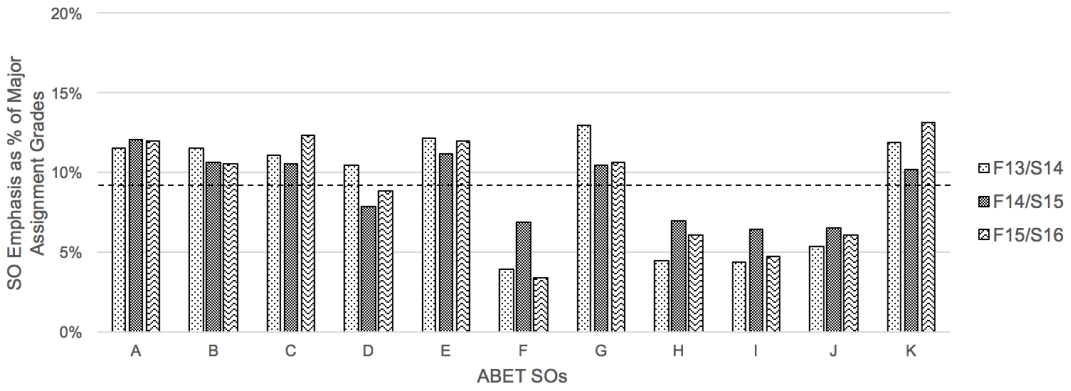

Figure 3.2. Graphical depiction of Table 3.4 FinalSO% data illustrating SO assessment emphasis for years 2014 (F13/S14), 2015 (F14/S15), and 2016 (F15/S16) of the ME Capstone class. Note the average FinalSO% value across all semesters and SOs (9.1%) is shown as a dashed line.

Variation of SO% values between fall and spring semesters in relation to combined fall-spring values was determined using a similar tabulation of FinalSO% values at the semester level. As shown in Tables 3.5 & 3.6 below, SO assessment emphasis for fall and spring semesters includes the same SOs but in a different relative order. Fall FinalSO% data indicates that the six KSOs assessed over the three academic years under study are: (g), (k), (a), (c), (e), and (b); spring FinalSO% data orders the KSOs assessed as: (a), (b), (e), (k), (c), and (g). Fall FinalSO% data also demonstrates SOs assessed the least in ME capstone include (i), (h), and (f), whereas the spring FinalSO% data points to SOs (f), (i), and (j). The largest shifts in assessment emphasis were observed for SOs (d) and (k) in the fall and (f) and (j) in the spring.

Table 3.5. Fall semester FinalSO% distributions. Note FinalSO% values 10% or greater are shown in **bold**.

ABET SO	Fall 2013	Fall 2014	Fall 2015	Average SO %	Max – Min Delta
(a)	**10.7%**	**13.3%**	**12.3%**	**12.1%**	2.7%
(b)	**10.8%**	**10.4%**	9.5%	**10.2%**	1.3%
(c)	**11.5%**	**11.4%**	**13.2%**	**12.0%**	1.9%
(d)	**13.1%**	7.5%	8.8%	9.8%	5.6%
(e)	**10.9%**	**12.3%**	**12.3%**	**11.9%**	1.4%
(f)	3.6%	6.7%	4.2%	4.8%	3.1%
(g)	**14.4%**	**11.2%**	**12.1%**	**12.6%**	3.1%
(h)	3.1%	6.0%	4.3%	4.5%	2.9%
(i)	3.0%	5.5%	4.2%	4.2%	2.4%
(j)	6.7%	6.1%	4.4%	5.7%	2.2%
(k)	**12.2%**	9.6%	**14.7%**	**12.2%**	5.1%

Table 3.6. Spring semester FinalSO% distributions. Note FinalSO% values 10% or greater are shown in **bold**.

ABET SO	Spring 2014	Spring 2015	Spring 2016	Average SO %	Max – Min Delta
(a)	**12.4%**	**10.9%**	**11.7%**	**11.7%**	1.5%
(b)	**12.4%**	**10.9%**	**11.7%**	**11.7%**	1.5%
(c)	**10.7%**	9.8%	**11.5%**	**10.7%**	1.7%
(d)	7.9%	8.2%	8.9%	8.3%	1.1%
(e)	**13.3%**	**10.1%**	**11.7%**	**11.7%**	3.2%
(f)	4.3%	7.1%	2.6%	4.6%	4.5%
(g)	**11.6%**	9.7%	9.3%	**10.2%**	2.4%
(h)	5.8%	8.0%	8.0%	7.3%	2.2%
(i)	5.8%	7.3%	5.2%	6.1%	2.1%
(j)	4.1%	7.1%	7.7%	6.3%	3.6%
(k)	**11.6%**	**10.9%**	**11.7%**	**11.4%**	0.8%

Non-FinalSO% data was evaluated for each assignment and SO to determine how the differences in FinalSO% data across several semesters and academic years manifested. Five of the six major assignments in the fall semesters (not including final course grades, assignments 2 – 6) exhibited at least one large shift in SO assessment emphasis (i.e. – change in SO% values greater than 5%), either year over year or across years. Three out of these five assignments (assignments 2 – 4) exhibited large shifts in four or more SO% values, including SOs (b), (e), and (f). Each of the eleven SOs displayed large shifts in assessment emphasis across the three fall semesters in study.

Comparisons of SO% values at the assignment level for spring semesters found that five out of seven assignments exhibited large shifts in SO assessment emphasis. Only two out of the five assignments experienced large shifts in four or more SO% values (assignments 10, 12, and 14). Similar to the FinalSO% data at the academic year and semester level, many of these positive or negative shifts in assessment emphasis between the first and second years were reversed between the second and third years for fall semesters. For example, assessment emphasis of SO (a) in assignment 2 increased by 6% between the fall 2013 and 2014 semesters but decreased by the same 6% between the fall 2014 and 2015 semesters. A similar pattern was not observed in spring semesters, likely due to the curriculum and rubric changes in 2016 for the major assignments under analysis.

3.3 Academic Performance Evaluation Methods and Results

With the SO scoring activity completed for all applicable assignments and semesters, student team grades were reviewed to determine any deficiencies prior to any subsequent appraisal. An important issue immediately identified during the cursory evaluation of student grades was that several assignments were assigned letter grades (A, A-, B+, etc.) while others were assigned point value or percentage grades. To facilitate comparative analysis across assignments and semesters, all letter grades were mapped to equivalent percentage values using points from the standard scale provided by the course instructor in the syllabus to maintain integrity of overall grading data (Table 3.7). Assignments with recoded and non-recoded grades used in analysis are shown in Table 3.8. As mentioned previously,

a complete one-to-one comparison of student performance across all major assignments could not be made due to the significant changes to major assignments in the spring 2016 semester; in lieu of this, grades on assignments 9, 11, 13, 14, and 15 were used for spring 2016 data.

Table 3.7. Student grade recoding map.

Letter Grade	Recoded Score
A	95%
A-	80%
B+	79%
B	72%
B-	65%
C+	64%
C	57%
C-	50%
D+	49%
D	42%
D-	35%
F	34%

Table 3.8. Recoded and non-recoded major assignments list by semester. Note coded final course grades are in **bold**.

Semester	Recoded major assignment(s)	Non-recoded major assignment(s)
Fall 2013	6, **7**	1, 2, 3, 4, 5
Spring 2014	8, 9, 10, 11, 12, 13, 14, **15**	N/A
Fall 2014	**7**	1, 2, 3, 4, 5, 6
Spring 2015	**15**	8, 9, 10, 11, 12, 13, 14
Fall 2015	**7**	1, 2, 3, 4, 5, 6
Spring 2016	**15**	9, 11, 13, 14

Once student team grades for major assignments were compiled and recoded as needed across all semesters, student performance was evaluated using unpaired t-Tests assuming unequal variances to determine statistical significance of differences and compare student grades amongst all subgroups for a given assignment (i.e. – comparing fall 2013 student grades on assignments 1–6 to student grades for the same assignments in fall 2014 and fall 2015). The null hypothesis for these tests was that no difference would be found between average

student grades across semesters, with a selected significance level of $\alpha = 0.05$. This approach yields greater risk of Type I errors (incorrectly reject true null hypothesis) but gave additional insights that alternative methods such as ANOVA may not identify, including a directionality of relation between the two samples instead of simple equality/non-equality across semesters (i.e. – alternative hypotheses of “x is greater than y” rather than “x and y are not equal”) [7]. A total of 39 independent samples t-Test comparisons of student performance across major assignments and final course grades were made, with 21 t-Tests for fall and 18 for spring. As shown in Table 3.9 below, 22 of the 39 t-Tests (or roughly 56%) found statistically significant differences in student grades. Taken as a whole, grade differences found to be statistically significant for fall assignments trended positive with passing time (i.e. – fall 2014 scores greater than fall 2013) whereas spring assignments trended negative (i.e. – spring 2015 scores less than spring 2014). Quantifying this, the average difference in mean grades observed on fall assignments listed in Table 3.9 is +12.3% while the average for spring assignments is -3.3%.

Table 3.9. Academic year t-tests. Note comparisons of final course grades are in **bold**.

Semesters in Comparison	Assignment Number	Difference in Means Observed	Significance (P-value)
F13-F14	2	+9.7%	0.0192
F13-F14	3	+17.4%	0.0014
F13-F14	4	+20.9%	3.6E-05
F13-F14	5	+15.0%	0.0005
F13-F15	1	+9.2%	0.0011
F13-F15	2	+13.2%	0.0019
F13-F15	3	+16.9%	0.0017
F13-F15	4	+17.1%	0.0003
F13-F15	5	+9.4%	0.0168
F14-F15	5	-5.6%	0.0041
S14-S15	8	-7.8%	0.0006
S14-S15	10	-5.4%	0.0203
S14-S15	14	+5.5%	0.0010
S14-S16	9	+5.2%	0.0368
S14-S16	11	+3.4%	0.0346
S14-S16	13	-10.6%	0.0009
S14-S16	14	-14.2%	1.0E-05
S15-S16	9	+13.8%	0.0010
S15-S16	11	+7.0%	3.4E-05
S15-S16	13	-12.3%	0.0002
S15-S16	14	-19.7%	2.4E-08
S15-S16	**15**	**-5.0%**	**0.0028**

More grade differences were found to be significant between spring assignments than fall, even though more fall assignment grade comparisons were made. This may be attributed to a number of factors, including the necessary recoding of all spring 2014 grade data or the change in grading and instruction faculty in spring 2016, among others. Overall, fall 2013 and spring 2014 grades exhibited the largest variance from their respective comparison groups with 9 and 7 statistically significant t-Test comparisons, respectively. Only one significant difference in mean final course grades was found – that of spring 2015 and spring 2016 with an observed reduction in average final grades of 5%. It is also worth noting that no t-Tests found average fall 2013 grades to be higher-achieving than fall 2014 or 2015 values. Two assignments demonstrated statistically significant

differences in performance between all three years in analysis (Assignments 5 and 14). Both assignments failed to show a continuous positive trend in student grades with an average performance increase between year 1 and year 2 but a decrease between years 2 and 3.

CHAPTER 4: CONCLUSIONS & FUTURE WORK

4.1 RQ1: Writing Fellows in Capstone

In short, the implementation of WFs in the ME capstone course as UNR has shown qualitative signs of success, yet more work is needed to improve both the program itself and the instruments used to assess its effectiveness. From an institutional perspective, the WF program leverages existing resources from the UWC and allows for focused writing support at low costs. Student reactions to the WF have been generally positive with most students agreeing that the WF program should be continued. Early assessment on the effectiveness of the program suggests that the WFs do contribute to student learning. However, these assessment efforts have highlighted a critical aspect for improvement. Namely, the engineering faculty needs to work more closely with the WFs in communicating expectations to the students.

Recommendations for WF program implementation in engineering capstone courses at other institutions include establishing frequent interactions between the WF and instructional team to ensure expectations of student writing proficiency are fully detailed for both the overall capstone course and individual writing tasks, involving the WF in writing task rubric development to solidify performance expectations quantitatively, and identification of other pre-capstone engineering courses in the undergraduate engineering curriculum where WFs may be effectively implemented earlier in the student's educational career. Additionally, special attention should be given to evaluate any assessment instruments used to evaluate the performance of WFs relative to capstone course writing skill

development objectives to ensure their validity and robustness. These areas offer opportunities for improving WF deployment, and future work will focus on using the observations of students, the capstone instruction team, and WFs to enhance the implementation of the WF program within the ME capstone course at UNR. Other areas for future work consist of determining the scope of potential future WF and team mentor deployment, refining current assessment methods, and developing writing task rubrics that capture incremental writing skill development goals capable of fulfilling overall course objectives.

4.2 RQ2 & RQ3: ABET Student Outcome Assessment in Capstone

The relative levels of key SO assessment are in line with local programmatic objectives and in general agreement with opinions of engineering capstone instructors surveyed when asked which SOs were most appropriate to evaluate in capstone [1]. With regard to the methods used, the process of rating and ranking levels of SO assessment in each major assignment proved to be more difficult for certain SOs than others. The author recognizes that while this methodology attempts to quantify relative levels of SO assessment, its overall robustness, accuracy, and precision may be influenced by the end user / researcher. All quantitative results should be interpreted qualitatively as instructor experience and common sense may dictate if such an approach is used in other courses. Despite numerous changes to the curriculum and instruction staff, the data demonstrated SO assessment emphasis for major assignments in ME capstone has remained largely unchanged over the past three years. The data demonstrates that relative

levels of emphasis differ for each SO between fall and spring semesters but both share key SOs which are assessed more than others.

Given its status as an accrediting board, the various accreditation commissions of ABET (including the Engineering Accreditation Commission, EAC) periodically review their accreditation requirements to ensure relevancy and alignment with industry good practices. As of the time of writing, the EAC is reviewing proposed amendments to streamline Criterion 3 SOs in an effort to ensure ABET "[keeps their] criteria relevant, fresh and compelling" and "measurable" [2]. Many engineering educators argue that the proposed SO modifications do not fulfill larger gaps in ABET requirements (such as "minimal requirements for educational breadth") [3] and the justifications for changing overlook the large body of research surrounding SO assessment in engineering programs. In any case, the general objectives of the proposed and current SOs are similar enough that a subsequent analysis using the methods described here would likely yield common thematic results. Future work on coursework SO assessment would be to evaluate and quantify the test-retest and interrater reliability of the SO SCORE assignment instrument, developing a survey instrument for students to provide feedback on perceptions of SO assessment, and experimenting with the scope of SO SCORE coding level resolution, all in an effort to ensure overall quality and accuracy of interpretations and to reduce possibilities for researcher bias the influence the assessment data [4].

Analysis of student grades on major assignments in the ME capstone course illustrated significant differences across the assignments and years under

investigation. General trends in student performance show increased performance versus time for fall semesters but decreased performance versus time for spring semesters. Differences in student grades may be due to any number of factors including the knowledge levels of the students themselves, utilization of numerous graders across assignments and semesters, and modifications to curriculum or grading practices, among others. When extended to analyzing student grades, the KSO assessment data failed to demonstrate a relation between levels of KSO assessment in ME capstone and student academic achievement, possibly due to actual non-existence of the relation, predictor collinearity issues, or from complications stemming from SO scoring methods and student grade recoding.

4.3 Other Impacts

It is important to note that the implementation and assessment activities described in this thesis can easily be adapted to other undergraduate engineering courses. Course designers and engineering program faculty may find that use and assessment of a program such as the WF benefits students by supplementing existing curriculum, as evidenced through their implementation within technical degree programs across the United States. To ensure programmatic accreditation requirements are met, engineering departments would likely benefit from periodic review of course curriculum and student performance at the assignment level, if for no other reason than to note trends that signify course changes may be required. Although assessment of writing skills and SOs in engineering capstone

courses remains difficult, it is the vital element with which needed changes to greater engineering instruction practices can be detected.

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