Evaluating ABET Student Outcome (3) in a Multidisciplinary Capstone Project Sequence

Dr. Nicholas A. Baine, Grand Valley State University

Nicholas Baine, Ph.D., P.E., is an Associate Professor in the School of Engineering at Grand Valley State University. His expertise is in the design of electrical control systems and sensor data fusion. As an instructor, he specializes in teaching first-year courses, probability and signal modeling, and control systems. He has also been active in ASEE, serving on the board of the North Central Section, and publishing papers on a variety of topics which include ABET accreditation and first-year course design.

Dr. Karl Brakora, Grand Valley State University

Karl Brakora is an Assistant Professor in the area of electrical engineering at Grand Valley State University. He previously worked for small companies and as an independent defense contractor to develop advanced ceramic materials, radar, and novel electronic fabrication methods applied to the development of guided munitions, electro-optic imaging systems, and medical devices. At GVSU he maintains electronic prototyping courses and co-created the School of Engineering's professional ethics curriculum, which has become his primary academic focus. Karl received his Ph.D. in Applied Electromagnetics from the University of Michigan.

Dr. Christopher P. Pung P.E., Grand Valley State University

Dr. Pung has interests in experiential learning, design processes and student teams.

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Abstract

In 2017, ABET published a revised list of student outcomes detailed under ABET General Criterion 3, which replaced outcomes (a) through (k) with outcomes (1) through (7). The revised student outcomes place greater emphasis on measuring students' ability to consider a wide range of factors in engineering situations and to be able to communicate and work with a wider range of stakeholders. Outcome (3) is like the previous criterion's outcome (g), which requires that students have "an ability to communicate effectively". This paper describes an assessment method for the current ABET student outcome (3), which assesses "…an ability to communicate effectively with a range of audiences."

The capstone project sequence at Grand Valley State University (GVSU) is well-suited to assess students' ability to communicate with a wide range of audiences due to their interactions within a team, with a customer, and with the general public at the conclusion of their project. To complicate the assessment, ABET requires each program to be assessed independently without data from students of different majors, even when students with multiple majors take the same course. GVSU's emphasis on the use of multidisciplinary teams drawn from multiple engineering programs and interacting with a wide variety of people including the public makes this an ideal opportunity to assess outcome (3), but it also complicates the disaggregation of data.

The assessment tools presented in this paper use faculty advisor evaluations to measure key elements of communication for outcome (3) in a multidisciplinary industry-sponsored design and build project. These elements include Clarity & Audience Focus, Organization, Presentation Mechanics, Visual Aid Usage, Professionalism, Style, and Format. This assessment tool disaggregates team performance data to determine an independent metric for each program major while preserving the multidisciplinary nature of the capstone projects. Data from the capstone sequence at GVSU is used to demonstrate these methods. The result of the methods detailed in the paper is a clear, stable, and independent metric that can be used to assess outcome (3) for each program major in a multidisciplinary capstone project.

Introduction

In the revised ABET General Criterion 3 (Student Outcomes), outcomes (a) through (k) have been replaced with (1) through (7). Outcome (g) used in 2017 and before required only "…an ability to communicate effectively." [1] This paper presents methods to measure ABET student outcome (3) which is written as "…an ability to communicate effectively *with a range of audiences*." [2] There has been several attempts to create technical communication programs that reach a wide range of audiences [3], [4], and to get those attempts to conform with ABET accreditation standards [5]. We have chosen to evaluate students' ability to communicate with a range of different audiences during a two-semester, industry-sponsored senior project. This has the advantage that student project groups will encounter a variety of different audiences naturally

through the course of their activities, rather than relying upon the instructors to create artificial or curated experiences.

GVSU offers six engineering programs: Computer Engineering (CE), Electrical Engineering (EE), Mechanical Engineering (ME), Product Design and Manufacturing Engineering (PDM), Biomedical Engineering (BME), and Interdisciplinary Engineering (IE). Students from all the programs enroll in the same capstone course sequence. Students in this sequence are placed in teams of three to six to work on a unique industry sponsored, multi-disciplinary, design-build-test project under the supervision of a faculty advisor. The projects are completed over the course of two semesters spanning from January to August and traditionally cover topics related to industrial automation, measurement, product design, product testing, inspection, and measurement devices. Capstone projects are proposed by a diverse range of industrial sponsors and are selected to be sufficiently complex, difficult, and multi-disciplinary that they could not be completed by a single student or a small subset of students within a project group.

Evaluation Methods

ABET outcome (3) requires "an ability to communicate effectively with a range of audiences." In this statement, we take an audience-focused interpretation of "communicate effectively;" we take it to mean a demonstrated ability "clearly and efficiently communicate the ideas, techniques, results, or outcomes relevant to the audience."

We divide effective communication into the following elements:

- Clarity & Audience Focus: The team articulates ideas clearly and concisely while addressing the concerns and focus of the audience.

- Organization: The team structures and organizes their presentation in a way that indicates a clear statement of purpose, logical flow of thoughts, and summary to enhance audience comprehension.

- Presentation Mechanics: The team presents the material in a way appropriate to the audience and thoughts conveyed. This includes elements such as spelling, grammar, citations, and formatting, in written communication. In spoken presentations it includes directly addressing questions, the avoidance of distracting communication habits, using appropriate and professional speech, etc.

- Visual Aide Usage: The team graphically presents relevant information to the audience that is difficult using only block text or spoken words. This includes the effective use of tables, figures, illustrations, and process flows.

- Professionalism: The appearance of the student team and their communication materials is neat and professional.

- Style: The team focuses its communication on its intended audience and can maintain audience attention and interest. The presentation is clean, clear, and aesthetically pleasing. If it is a presentation, dress and attire is appropriate.

- Prescribed Length and Format: The team does not provide an over-abundance of information to the intended audience while addressing the most pressing concerns and interest of that audience. Technical documents will follow a prescribed and expected format.

There are several taxonomies of "audience" in technical writing style manuals [6]. We have used a simplified definition of "a range of audiences" that a student project is likely to encounter. These are:

- An interested technical audience: This includes the project advisors, some project sponsors, and other parties that will have to technically interreact with the deliverables of the product. The relevant information that these audiences wish to know are the implementation of the deliverable product, its theory of operation, maintenance and troubleshooting, and a demonstration of the technical competence in its design to have confidence in the product.

- A disinterested technical audience: This includes technically competent people without a stake in the outcome or operation of the product where their interest is primarily restricted to professional curiosity, learning about new ways to do things, or future development ideas. The relevant information these audiences wish to know is what the deliverable does, its principal of operation, and prospective information about how it could be adapted to other applications.

- An interested non-technical audience: This includes some sponsors and other parties with an interest in the deliverable but without the ability to technically evaluate the design or the obligation to implement or maintain the product. Common examples would be corporate or marketing representatives. The primary interest of such audiences is what the product does, what problems can it be applied to, and what are the associated costs or risks.

- A disinterested non-technical audience: This includes people with the least stake in the outcome of a project but makes up most of the population. This includes parents, corporate visitors, university administration, and press. The interests of this population are largely to learn of new capabilities, devices, or interesting solutions. To the extent they are interested in methods or techniques, it is largely restricted to novel or counter-intuitive solutions, or solutions that demonstrate an elegance or technical mastery expressed in a way that they can understand.

There are several opportunities to evaluate a student team's communication through the course of the two-semester capstone project. Each of these communication opportunities focus on different, yet overlapping, audiences.

The first opportunity is termed the "scoping document." This is a communication from the team to the sponsor with input from the faculty advisors. This document details the problem, the scope of the project, the deliverable requirements, and generally spells out what a successful outcome will entail. The document becomes the basis of an agreement between sponsor and the student

team, and so it employs more legalistic language than other communications. This is generally presented to an interested technical and interested non-technical audience.

Next is the "peer presentation." During this communication, the student team presents their design concepts to the assembled senior class and project faculty. Presentations are capped at 10 minutes and efficiency of communication and visual presentation is critical [7]. The designs are assessed by the audience for technical feasibility and their design choices in selecting a concept. The audience for this is a disinterested technical audience.

At the completion of the first semester, the student team issues a detail design report. This is issued prior to building the deliverables and represents the intentions of the student team in the product they will deliver. This is presented to the industry sponsors for their comment and feedback. They will sometimes evaluate it for technical feasibility but are typically more focused on whether the design presented comports with their vision for the deliverable. This is an interested technical audience.

At the conclusion of build-phase of the design, the students will issue relevant documentation for the project deliverables. These may take the form of a "user manual," "reference manual," or often multiple documents targeted at different users who interact with the deliverable differently. These will typically include installation instructions, operating procedure, maintenance procedure, assembly diagrams, along with all the final design documents such as part drawings, schematics, CAD, and source code. The audience for these communications is a mix of interested technical and non-technical users of the deliverable and presents the largest challenge for calibrating the communication to the intended audience.

Finally, the student teams present their project during a project presentation which coincides with other events such as graduation. It is well-attended by local industry representatives, university administrators and faculty, and students' families. Students exhibit their deliverables with the aid of posters, videos, and demonstrations the course of the day. The primary audiences are disinterested and non-technical though they will need to field technical questions.

The effectiveness of the students' communication is evaluated by the team's faculty advisor who has been party to each of these communications while providing feedback to the student team. At the close of a senior project, faculty advisors compete a survey regarding how they believe their students performed in each of the elements of "effective communication" listed above. These results are tabulated for analysis and disaggregation.

Calculation and Disaggregation

Multidisciplinary capstone design courses are encouraged by both professional societies and ABET due to the strong pedagogical benefits to this approach. This also mimics the professional environment most engineers will encounter upon graduation. However, the data for these teams must be disaggregated to evaluate outcomes for each discipline. At GVSU we have chosen to employ a statistical disaggregation method.

A weighted average is used to determine the amount of influence each discipline has on the team's score for Outcome 3. For example, a team of only PDM majors would obviously only contribute to the PDM program score. Similarly, a team of two EE, two ME and one PDM would have a

score of 2, 2, and 1 respectively for their programs. This is expressed as mathematical formula in Equation 1.

$$\text{Program Score} = \frac{\sum_i^n s_i k_i}{\sum_{i=1}^n k_i} \quad (1)$$

where n = number of teams, S_i = score for the i[th] team, and k_i = number of students in that program on the i[th] team.

Results

This section presents the results of a recent assessment performed on the capstone project sequence at GVSU in 2022. There were 117 students who enrolled in the capstone courses and were placed on 24 teams. The breakdown of these teams by major program is shown in Table 1.

Table 1: Number of students from each program major on each team.

Team #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
EE	2	0	0	0	1	1	0	3	2	4	0	1	0	0	0	1	0	2	2	1	0	0	0	2
CE	3	0	0	0	3	0	0	4	2	1	0	0	0	0	0	0	0	3	1	0	0	0	1	2
PDM	0	1	1	1	0	1	0	0	0	0	2	0	3	4	0	1	1	0	0	1	1	0	0	0
ME	1	4	4	4	0	2	5	0	2	0	3	4	1	0	5	1	4	0	2	2	4	4	4	0
BME	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IE	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2 shows the individual team assessment scores from the assessment rubric in the appendix. The average for all metrics was above the score of 3, which is defined as meeting performance criteria; however, it is also shown that *visual aid usage* is the lowest metric and *style* is the highest metric.

Table 2: Individual team scores from assessment rubric.

					Team Number																		
	Average	Std Dev	Min	Max	1	2	3	4	5	6	7	9	10	11	12	15	16	17	18	19	21	23	24
Clarity & Audience Focus	3.5	0.4	3.0	4.0	4	4	4	4	3	4	3	3	3	3	3	4	4	4	4	4	3	4	3
Organization	3.4	0.4	2.5	4.0	3	4	4	4	3	4	3	3	4	3	4	4	4	3	3	3	3	4	3
Presentation Mechanics	3.5	0.4	3.0	4.0	4	4	4	4	4	4	3	4	3	3	4	4	4	3	4	3	3	4	3
Visual Aid Usage	3.3	0.5	2.5	4.0	3	4	4	3	4	4	3	4	3	3	3	4	3	3	4	3	3	3	3
Professionalism	3.6	0.5	2.3	4.0	4	4	4	4	3	4	2	4	4	4	4	4	3	4	4	4	3	4	3
Style	3.7	0.3	3.0	4.0	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	3	4	4	3
Prescribed Length/Format	3.6	0.4	2.5	4.0	3	4	4	4	4	4	4	4	4	3	4	4	4	3	4	3	4	4	3
Outcome 3 Average	**3.5**	**0.3**	**2.9**	**4.0**	**3.4**	**4.0**	**3.9**	**3.6**	**3.6**	**3.9**	**3.1**	**3.7**	**3.6**	**3.3**	**3.5**	**3.7**	**3.4**	**3.4**	**3.9**	**2.9**	**3.4**	**3.6**	**2.9**

To determine the score for an individual program, the scores from Table 2 were weighted by the number of students for each program (Table 1) using equation (1). For example, the result of this calculation for the ME program is shown in Table 3. In this case, the average score for the ME program major is 3.5 with the strongest element being *Style* (score of 3.7) and the weakest element being *Visual Aid Usage* (score of 3.2). The average weighted assessment scores for each program are shown in comparison to the score for all students in Table 4. This shows that unique assessment scores were calculated for each outcome element (performance indicator) for each of the majors, effectively providing disaggregates results. The results for the Biomedical Engineering (BME) and Interdisciplinary (IE) were excluded from Table 4 due to their low sample size of one student each.

Table 3: Weighted assessment scores for ME program major.

Team Number					1	2	3	4	5	6	7	9	10	11	12	15	16	17	18	19	21	23	24
Number of ME Students in Team					1	4	4	4	0	2	5	2	0	3	4	5	1	4	0	2	4	4	0
Outcome Element	**Avg**	**StDev**	**Min**	**Max**	Scores for each team are weighted by the number of students in the major assessed																		
Clarity & Audience Focus	3.5				4	16	14	16	0	8	17	6	0	10	12	18	4	15	0	7	13	14	0
Organization	3.5				3	16	16	14	0	7	17	6	0	9	14	20	4	12	0	5	13	14	0
Presentation Mechanics	3.5				4	16	14	14	0	8	15	8	0	10	14	18	4	13	0	6	13	16	0
Visual Aid Usage	3.2				3	15	16	12	0	7	13	8	0	9	13	18	3	13	0	5	12	12	0
Professionalism	3.6				4	16	16	14	0	8	12	8	0	11	15	20	3	15	0	7	13	16	0
Style	3.7				4	16	16	16	0	8	18	8	0	10	15	18	4	15	0	6	15	16	0
Prescribed Length/Format	3.7				3	16	16	16	0	8	18	8	0	10	14	20	4	13	0	5	15	14	0
Outcome 3 Average	**3.5**	**0.3**	**2.9**	**4.0**	3	4	4	4	N/A	4	3	4	N/A	3	3	4	3	3	N/A	3	3	4	N/A

Table 4: Average weighted assessment scores for Outcome 3 for Electrical Engineering (EE), Computer Engineering (CE), Product Design and Manufacturing Engineering (PDM), and Mechanical Engineering (ME)

	All	EE	CE	PDM	ME
Clarity & Audience Focus	3.46	3.31	3.34	3.63	3.51
Organization	3.35	3.25	3.06	3.43	3.46
Presentation Mechanics	3.53	3.44	3.66	3.54	3.51
Visual Aid Usage	3.26	3.21	3.41	3.28	3.24
Professionalism	3.62	3.71	3.66	3.65	3.63
Style	3.71	3.68	3.72	3.72	3.74
Prescribed Length/Format	3.63	3.56	3.56	3.69	3.67
Outcome 3 Average	**3.51**	**3.46**	**3.45**	**3.60**	**3.52**

Discussion

The results in the previous section show that this method provides unique scores for each of the outcome elements (performance indicators). The data indicates that all the programs met the target score of 3, which is defined as satisfactory, and that only one team (Team 24) earned a score below the target value. While the scores for each program are unique, there is not much variability between them. This is not surprising given that instruction related to Outcome 3 is predominantly done in courses in common between the programs, which include general education writing

courses, the first-year engineering courses, mandatory cooperative education courses, and the senior design courses.

Conclusions

Outcomes (1)-(7) are distinguished from the prior standard of (a)-(k) by the fact that they place greater emphasis in a wholistic approach to engineering education, which can be further enhanced with multidisciplinary experiences. ABET does not provide methods or examples for measuring or disaggregating data regarding the new outcomes and relies on the institutions to create the needed tools, which fit their programs. For the program at GVSU, there was a need for a specialized assessment tool to measure student outcome (3) of Criterion 3 within our senior capstone sequence. The challenge was that all assignments and project work are completed in multidisciplinary teams, making it more challenging to have disaggregated assessment data.

The assessment tool and analysis method presented in this paper provides a way of assessing multidisciplinary teams for this ABET student outcome while still obtaining unique and relevant results for each program being assessed. This is far better than performing an assessment at a less ideal point in the curriculum or removing the multidisciplinary element to allow for data disaggregation.

References

[1] ABET Engineering Accreditation Commission, "Criteria for Accrediting Engineering Programs," 2017.

[2] ABET Engineering Accreditation Commission, "Criteria for Accrediting Engineering Programs," 2022-2023.

[3] N. J. Dimmit and J. Mohammed, "Strategies for improving technical communication effictiveness skills in a middle east engineering program.," in *American Society for Engineering Education*, San Antonio, TX, 2012.

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Appendix: Faculty Assessment Rubric (1 of 2)

Outcome element	1 Below Performance Expectations	2 Progressing to Performance Criteria	3 Meets Performance Criteria	4 Exceeds Performance Criteria
Clarity & Audience Focus	Key points are not organized, and communication not clearly articulated in a concise manner; Range of audience and audience focus was not considered or effective (excessive or insufficient detail)	Key points are communicated but not clearly articulated in a concise manner; Communication is disjointed, superfluous or difficult to follow; Range of audience may not have been considered and audience focus limited or ineffective (excessive or insufficient detail)	Key points are communicated but sometimes not clearly articulated in a concise manner; Communication is occasionally disjointed, superfluous or difficult to follow; Range of audience considered, and audience focus satisfactory/effective (concise with sufficient detail)	Articulates ideas clearly and concisely; Range of audience considered, and audience focus properly targeted and effective (concise with sufficient detail).
Organization	Communication has limited or no structure or organization; presentation phrasing is not well articulated with an introduction, logical flow of thoughts, and summary, making overall comprehension difficult	Communication has some element of structure/organization; presentation phrasing has limited articulation with an introduction, logical flow of thoughts, and summary, making overall comprehension limited.	Communication has a satisfactory level element of structure/organization; presentation phrasing is satisfactorily articulated with an introduction, logical flow of thoughts, and summary to enhance overall comprehension.	Communication is well structured/organized; presentation phrasing is well organized/articulated with an introduction, logical flow of thoughts, and summary to enhance overall comprehension.
Presentation Mechanics	Has some major difficulties with the mechanical aspects of the communication? o Grammar, spelling, mechanics and use of proper English o Difficulty in articulation/projection of thoughts o Content or reference to content is limited; Message not properly conveyed. o Distracting communication habits (word choice/hesitations, rambling, disjointed thoughts, etc.) disturb presentation focus. o Lacking focus/ability to answer questions properly or provide overall comprehension. o Significant use of conversational language or slang	Has significant difficulties with the mechanical aspects of the presentation? o Grammar, spelling, mechanics and use of proper English o Some difficulty in articulation/projection of thoughts o Content or reference to content is somewhat limited; Message not properly conveyed. o Professional style to draw/connect/maintain audience attention (visual/written appeal, interesting content and presentation style) is sometimes lacking. o Some distracting communication habits (word choice/hesitations, rambling, disjointed thoughts, etc.) disturb presentation focus. o Focus/ability to answer questions properly or provide overall comprehension is sometimes lacking. o Some use of conversational language or slang	Has some minor difficulties with the mechanical aspects of the presentation? o Grammar, spelling, mechanics and use of proper English o Limited difficulty in articulation/projection of thoughts o Content or reference to content may occasionally be limited; Limited ability to convey message. o Professional style to draw/connect/maintain audience attention (visual/written appeal, interesting content and presentation style) is occasionally limited. o Limited distracting communication habits (word choice/hesitations, rambling, disjointed thoughts, etc.) disturb presentation focus. o Focus/ability to answer questions properly or provide overall comprehension is occasionally lacking. o Limited use of conversational language or slang	Presents well mechanically. o Grammar, spelling, mechanics and use of proper English o No difficulty in articulation/projection of thoughts o All content and reference to content allow message to be properly conveyed. o Professional style to draw/connect/maintain audience attention (visual/written appeal, interesting content and presentation style) adds to audience interest/focus. o No distracting communication habits (word choice/hesitations, habits, rambling, disjointed thoughts, etc.) disturb presentation focus. o Communication is properly articulated to provide clear focus/ability to answer questions properly and provide overall comprehension. o No use of conversational language or slang

Appendix: Faculty Assessment Rubric (2 of 2)

Outcome element	1 Below Performance Expectations	2 Progressing to Performance Criteria	3 Meets Performance Criteria	4 Exceeds Performance Criteria
Visual Aid Usage	Graphs, tables, equations or diagrams are used, but not properly referenced or formatted (including mathematical formatting for equations); Presentation includes errors, incomprehensible/unclear language or does not convey content effectively.	Uses graphs, tables, equations and diagrams, but application/formatting (including mathematical formatting for equations) are sometimes not used to support, explain or interpret information; Some errors or incomprehensible/unclear language or some language not conveyed effectively	Uses graphs, tables, equations, and diagrams, but occasionally not applied/formatted (including mathematical formatting for equations) to support, explain or interpret information; Occasional minor errors or unclear/incomprehensible language with most content conveyed properly	Uses graphs, tables, equations, and diagrams to support points—Proper references and formatting (including mathematical formatting for equations) to explain, interpret, and assess information; Presentation is error-free, clear/comprehensible, with content that is effectively conveyed
Professionalism	Physical work and (or) appearance is not presented neatly and in a professionally appropriate manner	Physical work and (or) appearance lacks neatness and attention to a professionally appropriate manner	Physical work and (or) appearance is satisfactorily presented in a neat and professional manner	Physical work and (or) appearance is presented neatly and professionally
Style	Communication style lacks proper level of formality or is inappropriate for the targeted audience and (or) assignment or lacks ability to draw/connect/maintain audience attention (visual/written appeal, interesting content and presentation style); frequent use of technical jargon or improper voice/tense results in misleading, confusing, or incorrect communications.	Communication style sometimes lacks proper level of formality or is inappropriate for targeted audience and (or) assignment or lacks ability to draw/connect/maintain audience attention (visual/written appeal, interesting content and presentation style); some technical jargon or improper voice/tense results in misleading, confusing, or incorrect communications	○ Communication style has proper level of formality but may be inappropriate for targeted audience and (or) assignment or lacks ability to draw/connect/maintain audience attention (visual/written appeal, interesting content and presentation style); limited use of technical jargon or improper voice/tense may result in misleading, confusing, or incorrect communications	Communication style is mature and professionally appropriate for the intended audience and (or) assignment and demonstrates an ability to draw/connect/maintain audience attention (visual/written appeal, interesting content and presentation style); no technical jargon or improper voice/tense
Prescribed Length/Format	Presentation is not concise and properly formatted; May be inappropriately short or excessively long; Key results omitted from presentation.	Presentation formatting and conciseness need attention: Inappropriate length may include excessive or insufficient detail	○ Presentation formatting and conciseness are satisfactory; Appropriate length with sufficient detail and technical content	Professional-level presentation with appropriate formatting and conciseness to accurately convey proper meaning; Appropriate length with sufficient detail and technical content