

Transitioning to the New ABET Student Outcomes: Architecture Development for a Systems Engineering Degree Program

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Abstract

Systems engineering degree programs are accredited by the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET). The accreditation process includes evaluation of a program's development and assessment of defined student outcomes (SO) (i.e. Criterion 3). These outcomes were recently revised by ABET for programs seeking accreditation in 2019 and later. The systems engineering degree program at the United States Air Force Academy has been twice accredited by ABET and will be revisited in 2020. In preparation for this visit and as part of its continuous improvement process, the Academy has revised its assessment architecture starting with a transition to the new ABET SOs. Following update to the new SOs, observable performance criteria (PC) were also revised. Updated traceability matrices were then developed to map into the Academy's cross-department, multidisciplinary curriculum. These curriculum mappings ensure full coverage of the SOs and serve as a basis for requests for assessment data to the various course directors. It has been observed that this strong traceability and clarity of data required of administering course directors is essential to building a tenable assessment process. This paper provides an overview and roadmap for other systems engineering programs seeking to revise their assessment architecture in preparation for ABET accreditation. The revision process, developed products of the assessment architecture, and observations on their implementation are provided.

Introduction

The Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology revised its Criterion 3 student outcomes in fall 2017. Seven (7) new student outcomes resulted, enumerated 1 – 7, replacing the previous eleven (11) student outcomes, designated a – k. These changes to Criterion 3 will be implemented for the 2019-20 accreditation review cycle. Engineering programs scheduled for general review in the 2019-20 cycle and later may begin transition to the new SOs as soon as possible, per ABET recommendation [1, p.38].

Most current ABET-accredited engineering programs will have a legacy assessment architecture that includes the ABET Criterion 3 SOs as a foundational component. The upcoming changes to SOs will typically require commensurate changes in assessment architecture below the SO level, revising student performance criteria that must support the new SOs as well as associated student evaluative data artifacts collected as performance evidence. The magnitude of change required will vary from program to program depending upon the status of the legacy assessment architecture. The United States Air Force Academy's SE Program assessment architecture was

in need of modest improvements and adaptations to revised institutional assessment needs in fall 2017, and thus, a substantial revision was undertaken addressing both ABET and institutional changes. The revision process described in this paper may provide some guidance and assessment process considerations for other engineering programs undertaking the transition to the new ABET Criterion 3 SOs. Academic programs developing an initial assessment architecture may also benefit from the structure and processes described.

Background

The Air Force Academy's undergraduate Systems Engineering (SE) program is scheduled for its third ABET accreditation review in 2020. As such, the program administrators have recently revised the program assessment architecture, including adoption of the new ABET SOs and an overhaul of evaluation processes and mechanisms. This paper will describe this revision effort and preliminary results.

Academic Program Description: The Academy's SE program [2], [3] has produced an average of 79 undergraduates per year over the previous six years. Administered across seven cooperating academic departments, the program provides core systems engineering education coupled with one of six available engineering concentration areas: aeronautical, astronautical, computer, electronics, human factors, or mechanical engineering [4]. Each SE student also participates in a year-long, senior engineering capstone experience [5] in which acquired knowledge and skills are practically applied in an engineering development project in response to a sponsor customer's needs. The Academy requires foundational core courses for all students provide a broad and thorough general undergraduate education in basic sciences, engineering, humanities, and social sciences [6].

The SE Program is governed by a board comprised of the heads of the seven cooperating academic departments and an SE academician holding the title of Director of Systems Engineering. The Director of SE also chairs a working level committee of teaching faculty representatives from each SE-cooperative department. Program modifications, including assessment changes, typically begin in the SE Committee as proposals that are ultimately presented with recommendations to the SE Board for dispositioning. Assessment and accreditation efforts across the program are led by a dedicated SE faculty member holding the title SE Curriculum and Assessment Manager.

ABET Criterion 3 Changes: Table 1 compares the expiring ABET EAC Criterion 3 SOs and the new set of SOs effective beginning 2019. A comparison of the new and expiring SOs reveals the following changes, organized by new SO:

Table 1: Comparison of Expiring and New EAC Student Outcomes

Expiring EAC SOs [1, pp. 4-5]:	New EAC SOs, Effective 2019 [1, pp. 39-40]:
<ul style="list-style-type: none"> 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 multi-disciplinary teams e) an ability to identify, formulate, and solve engineering problems f) an understanding of professional and ethical responsibilities of systems engineers 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) a knowledge of contemporary issues k) an ability to use the techniques, skills, and modern engineering tools necessary for systems engineering practice. 	<ul style="list-style-type: none"> 1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics 2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors 3) an ability to communicate effectively with a range of audiences 4) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. 5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives 6) an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions 7) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies

EAC SOs Effective 2019 [1, pp. 39-40]:

- 1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
 - Combines SO(a) and SO(e)
- 2) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
 - Combines SO(a) and SO(e)
- 3) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
 - Slightly modifies SO(c) language
- 4) an ability to communicate effectively with a range of audiences
 - Replicates SO(g)
 - Adds refining language about audiences
- 5) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
 - Combines SO(f) and SO(h)
 - Minor language modifications

- 6) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
 - Combines concepts of SO(d) and SO(k)
 - Language modifications
 - o Deletes “multi-disciplinary” from SO(d)
 - o SO(k) stated differently
 - o Adds general team activity items
 - o Deletes SO(k) references to engineering techniques, skills, and tools
- 7) an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
 - Restates SO(b) with revised language
 - Adds clause about engineering judgment and drawing conclusions
- 8) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies
 - Combines general concepts of SO(i) and SO(j)
 - Restates using more general language
 - o Deletes use of “life-long learning”
 - o Deletes reference to “contemporary issues”

Approach for Assessment Architecture Revision

The SE Program’s assessment architecture revision was driven primarily by the ABET EAC criteria changes, but also by fortuitously timed institutional assessment updates, and recent institutional assessment process feedback to the SE Program. Beyond the necessity to accommodate the new ABET criteria, the SE Program was required to support newly revised institutional-level assessment goals and to make assessment process improvements based upon feedback received in the previous year’s assessment cycle.

Goals: In early fall 2017 the SE Curriculum and Assessment Manager conducted an in-depth quality assurance review of the legacy assessment architecture. The review included examination of:

- the alignment of defined student performance criteria with program (ABET Criterion 3) Student Outcomes
- the alignment of student assessment data artifacts with the performance criteria they were intended to support
- assessment data collection and reporting mechanisms completed by course directors and teaching faculty each semester
- assessment program continual improvement process
- semester and annual results archiving and reporting methods

The legacy processes and products were appropriate for the SE Program's needs, but revisions were necessary to transition to the anticipated new SOs and some minor process improvements were prudent. Corrections were required for identified minor gaps and flaws, and a plan was needed for the integration of mechanisms addressing the revised institutional assessment requirements. The manager established five goals for assessment architecture revision:

- i. Ensure successful SE Program ABET accreditation in 2020 – Maintaining a quality academic program, including a process of continuing improvement and earning ABET validation, was paramount.
- ii. Rapidly transition to the new ABET SOs with appropriate new student performance criteria – Swift adoption of revised criteria would maximize longitudinal assessment data collection in the new format prior to the scheduled 2020 ABET review.
- iii. Improve efficiency in assessment data collection across courses for all assessment requirements – Administrative support for assessment is currently unavailable, and minimizing administrative burden on teaching faculty is a priority.
- iv. Improve the quality of assessment data artifacts collected – Refine data artifacts to be specific, quantifiable, objective student performance measures, to the extent feasible.
- v. Identify and correct gaps or errors in the legacy assessment architecture – Personnel turnover and a lack of administrative support had resulted in some minor disintegration of legacy assessment processes and products.

The SE program met these goals via the process defined in the IDEF diagram of Figure 1 and detailed in subsequent text. While these actions included changes to incorporate revised institutional assessment needs, to respond to institutional assessment feedback, and to correct minor gaps and errors, we will focus here on the assessment architecture revisions related to the transition to the new ABET EAC Criterion 3 Student Outcomes.

Map of Expiring SOs to New SOs: The first step in architecting the revised assessment process was to create a conceptual mapping between the expiring SOs (a – k) and the new SOs (1 – 7). The new SOs maintain the vast majority of assessment themes from the expiring set, and the mapping between the two provides pointers for longitudinal assessment continuity across the boundary of new SO adoption. The assessment manager and Director of SE proposed the mapping depicted in Table 2 as the closest conceptual match between the two SO sets. This mapping updates the 2017 SO analysis of Karimi [7]. This mapping was reviewed by the SE Committee for comment and feedback.

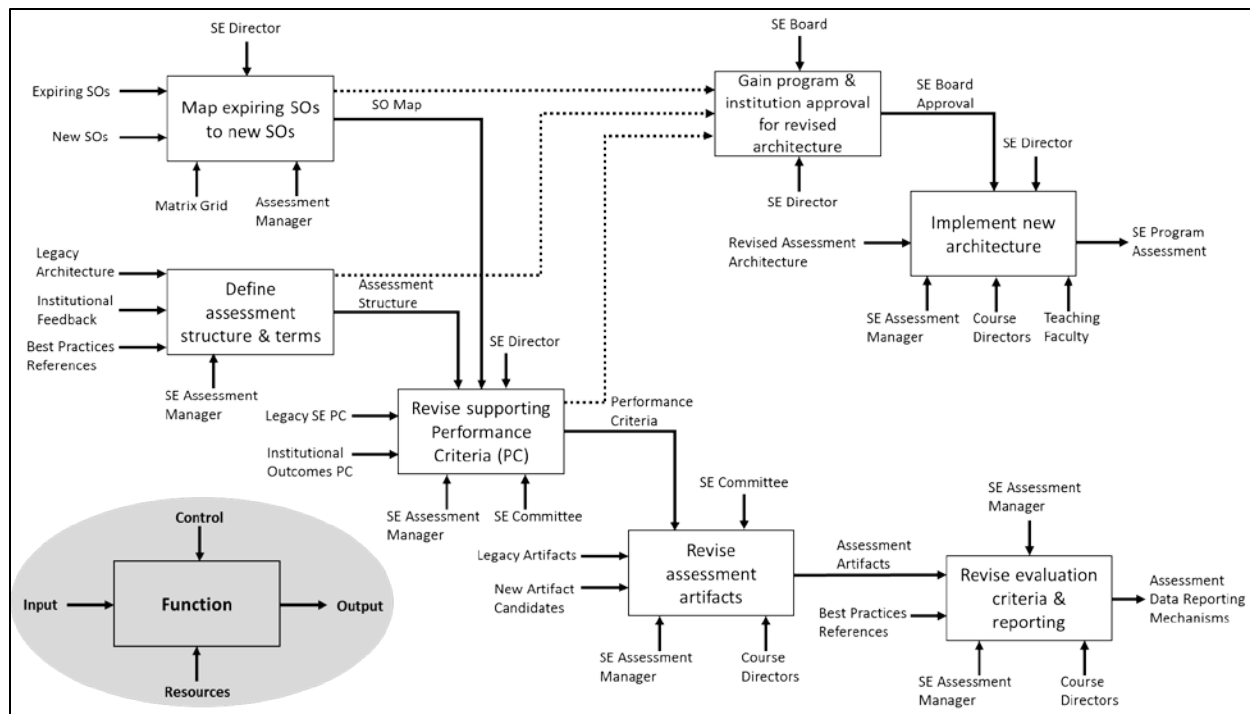


Figure 1: SE Program Assessment Revision Functional Process.

Defining Assessment Structure and Terms: For continuity and clarity of communication based in the legacy process, the assessment manager retained legacy terminology of assessment structures and definitions, and also added or refined others. The following structure and terminology are used across the SE assessment program:

Student Outcome (SO) – The ABET EAC and SE program-level outcomes for student acumen upon graduation, under which Performance Criteria are established [8]. (A.K.A. “program goals” [9, pp.28-34].)

Performance Criteria (PC) – Concrete measurable actions the student should be able to perform as indicators of achieving the overarching SO, and for which student assessment artifacts are collected [8]. (A.K.A. “learning objectives” [9, p.30], or “performance indicators” [8].)

Assessment Artifact – Specific data collected within the student learning experience, usually quantitative, providing evidence of associated Performance Criterion success or failure as defined by its associated evaluation criterion. (A.K.A. “assessment data” or “performance measures” [10].)

Evaluation Criterion – A predefined rubric describing student performance levels for an associated assessment artifact and defining performance thresholds for success and failure. (A.K.A. “grade, average, rating, ranking, performance value, etc.”)

Table 2: Mapping of expiring SOs to new SOs.

Expiring SOs a - k	New SOs 1 - 7						
	1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	3) an ability to communicate effectively with a range of audiences	4) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	6) an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	7) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies
(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 multi-disciplinary 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) a knowledge of contemporary issues							
(k) an ability to use the techniques, skills, and modern engineering tools necessary for systems engineering practice							

In the assessment architecture each SO is supported by multiple PC. In effect, PC should “operationalize” each SO, as recommended by Allen [9, p.30]. Each PC is evidenced by multiple assessment artifacts. In the SE program, assessment artifacts are typically collected by teaching faculty, accumulated by Course Directors, and aggregated as necessary by Course Directors or the Curriculum and Assessment Manager. Assessment artifacts are evaluated using evaluation criteria rubrics established by the Course Director of the specific course or learning experience in which the associated assessment artifact is collected. Evaluation criteria rubrics should be established in advance of artifact evaluation, based upon realistic student performance requirements for the artifact, and carefully crafted to ensure reliability [10]. The relationships among the SE program assessment structures are summarized in Figure 2. These connected structures form the critical template for linking data-driven support evidence to SOs.

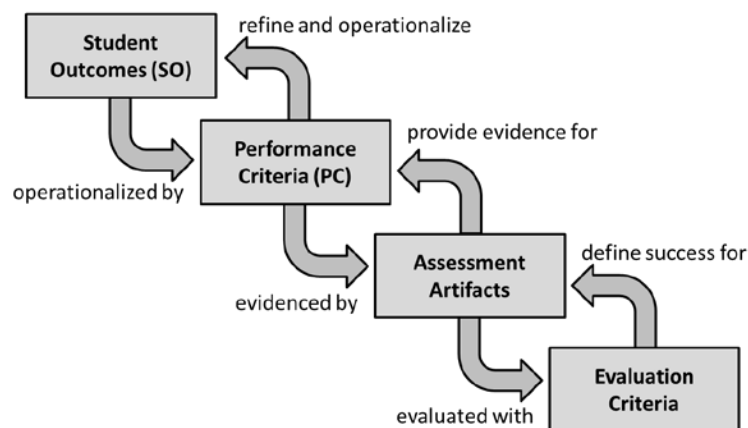


Figure 2: Relationships among SE Program assessment structures.

Revised Performance Criteria: The restructuring of ABET EAC Criterion 3 Student Outcomes seems to have resulted primarily in the conceptual merging of some preceding SOs and the revision of specific language. No uniquely new general concepts were added to the outcomes, and few detailed items were deleted. As such, the concepts and much of the language embodied in the performance criteria supporting the expiring SOs may be readily adapted to support the new SOs.

For the SE Program, the assessment manager utilized the mapping between old and new SO sets to identify expiring PC concepts and language that could be suitable for support of new SOs. This approach was clearly valid since the expiring PC had been successfully used for several years over which two successful ABET accreditation reviews were completed.

The following methods were used in combination to develop a proposed set of new PC in support of each of the seven new SOs:

- Merging the language of multiple expiring PC, where practical, to fit the performance intent of a new SO.
- Integrating new terminology to address the best practice of using action-oriented, measureable, behavioral criteria descriptions [9, p.28], per institutional feedback recommendations.
- Eliminating or changing current language that was nebulous and/or complex, and substituting language that is clearer and more descriptive, to address institutional feedback recommendation for ease of understanding.
- Editing the terminology of some PC to closely mirror the language of the Air Force Academy's institutional outcomes to which the SE Program is obligated to contribute evidence.
- Generating new language when legacy PC did not provide suitable language or proper fit to a new SO.
- Endeavoring to limit each new SO to just two (2) new PC, as feasible, to help achieve revision goal *iii*.

As an example of new PC development, consider the expiring SO (g) and new SO (3) related to *effective communication*, and the supporting PC associated with each:

Expiring SO (g): an ability to communicate effectively

PC g.1 Present information, concepts, and ideas in writing

PC g.2 Present information, concepts, and ideas orally

New SO (3): an ability to communicate effectively with a range of audiences

PC 3.a Impart a precisely stated and strongly supported central message using appropriate, relevant, and compelling content to illustrate thoughtful command of the subject.

PC 3.b Exchange ideas efficiently using a wide range of terminology and conventions common to the discipline of Systems Engineering.

Notice that new language has been incorporated using action-oriented, behavioral descriptions of the expected performance demonstration. The nebulous language of the expiring PC has been replaced with more descriptive terminology that better sets expectations for both student and faculty. These types of language enhancements contribute to the achievement of revision goal *ii*: *Rapidly transition to the new ABET SOs with appropriate new student performance criteria.*

The more descriptive PC language also helps subsequently in the identification or creation of appropriate assessment artifacts, thereby contributing to revision goal *iv: Improve the quality of assessment data artifacts collected.*

Additionally, the newly adopted PC language mirrors that of the Air Force Academy's institutional criteria for its *effective communication* outcome. With this overlap, the assessment artifacts collected by the SE Program for PC 3.a can be directly applied to the institutional assessment data request as well, as recommended by Hayder, et.al. [11]. This type of structuring helps to achieve revision goal *iii: Improve efficiency in assessment data collection across courses for all assessment requirements.*

Merging language adopted from multiple legacy PC is illustrated by the translation of expiring SOs (f) and (h) into new SO (4):

Expiring SO (f): an understanding of professional and ethical responsibilities

PC f.1 Know a professional code of ethics.

PC f.2 Identify and analyze ethical issues.

Expiring SO (h): the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

PC h.1 Analyze the environmental impact of a design solution.

PC h.2 Analyze the global, economic, and societal implications of a design solution.

New SO (4): an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

PC 4.a Describe engineering impacts and dilemmas for which sound ethical and professional informed judgment is required.

PC 4.b Explain how engineering design solutions may impact the environment, global and local society, and the economy.

In addition to merging the language of multiple PC, the more observable and measureable action terms *describe* and *explain* were used in lieu of *analyze* and *know*. The consolidation of four PC into two helps to achieve revision goal *iii: Improve efficiency in assessment data collection across courses for all assessment requirements*, while also contributing to revision goal *ii: Rapidly transition to the new ABET SOs with appropriate new student performance criteria.*

Revised Assessment Artifacts: Following the formal adoption of the revised SOs and PC by the SE Board, the SE Committee, at the recommendation of the assessment manager, tasked course directors to identify candidate assessment artifacts within their courses. The goal was to identify at least two high-quality assessment artifacts appropriate to each PC and to distribute artifact collection and evaluation equitably across SE courses, as feasible. Course directors identified

legacy graded events and activities that supported the new PC, and in some cases, proposed new assessment artifacts to be implemented in their courses. Course directors were not required to submit candidate assessment artifacts for all PC, but only for those PC that were logically connected to the subject matter and content of their courses.

The SE assessment manager evaluated the submitted candidate assessment artifacts, consulted with individual course directors and teaching faculty as needed for clarification and discernment of detail, and filtered to a final set of artifacts to be collected within each course. He revised the legacy curriculum matrix that maps PC to courses where the PC is covered topically. The curriculum matrix also indicates estimated depth of coverage for each PC (introduce, reinforce, or emphasize), and it identifies candidate (and final) assessment artifacts. Figure 3 depicts an excerpt from the revised curriculum map in-process, with SOs and PC listed in the left-most column and courses listed in the upper row. Matrix cell color-coding and textual designations define the specific PC-course relationships, and candidate assessment artifacts for each PC are listed in the right-most column.

In a small number of cases an insufficient number of appropriate candidate assessment artifacts were initially identified by course directors. The assessment manager initiated additional consultation with course directors to generate new or modified artifacts to complete and improve the curriculum map and artifact collection plan, and in two instances to discuss course content modifications to ensure proper learning experiences for PC topics.

Revised Evaluation Criteria, Reporting, and Analysis: With the completed curriculum matrix documenting PC topic coverage and assessment artifacts to be evaluated, course directors established evaluation criteria for their designated assessment artifacts using a common framework provided by the SE assessment manager – the Curriculum Review Letter. The legacy reporting mechanism was a text document form customized for each course and its associated PC and artifacts, and a modified version of this mechanism was retained in the revised assessment architecture. Course directors complete the Curriculum Review Letter with the following sequence of action for evaluation and reporting:

1. Assign each course assessment artifact a *success criterion* value, typically a numerical grade average, representing the boundary between satisfactory and unsatisfactory student performance. Example: Midterm Exam Part-1 Grade – 80% satisfactory performance threshold.
2. Compute and report the percentage of total enrolled students who met or exceeded the success criterion for each assessment artifact. Example: 77% of students exceeded the success criterion of 80% (23% unsatisfactory performance rate).
3. Color-highlight the reported success percentage in green, yellow, or red, indicating *satisfactory results*, *concern/warrants monitoring*, and *unsatisfactory results*, respectively. (Borderline success percentages may be highlighted yellow.)

DRAFT - IN PROCESS																		
SE SDs and PC	Cooper/Turner				Tucker				Richardson			Brault	Tidball	Cooper/Turner	Assessment Artifact Information			
	Courses	Institutional Core	SE310	SE320	SE405/406	SE311	SE301	SE336	SE477	DR310	DR312	Math Option 1	Math Option 2	CS211		BS373	Depth Options	Capstone
I = introduce, E = emphasis, R = reinforce, ■ = Candidate Assessment Point (in process)																		
SO-1: an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.																		
1.a. Frame and solve engineering problems using principles of engineering and science.	I	R	R	R	■	E/R						I		R	R	R/E	E	SE310: Final project report and briefing system development; Reliability & Maintainability Project; BS373: All 4 Labs or Group Design Project; Final Case Project. Capstone: Final Case Project.
1.b. Frame and solve engineering problems using principles of mathematics.	I	R	R	R		E/R		E/R		E/R	R	R	R				E	SE310: Reliability & Maintainability from Reliability & Maintainability question group; Case Project. SE336: 9 questions from LQSA questions corresponding to SE 336; TBD;
SO-2: an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors																		
2.a. Create and refine functional system requirements from a stated need.	I	R/E			■		R		R						I		E	SE310: Requirements & Feasibility Report; Project. BS373: LNS 3 Task Analysis & Capstone: PDR/SPR ratings -- via SE
2.b. Use a systematic process to develop and evaluate feasible candidate system solutions, identify alternatives, and select an appropriate solution.	I	R/E	E			E	R	R	R	E/R	I	E		R		R/E	E	SE310: GR-1 grade; Course grade. SE311: Final Case Project. Capstone: Final Case Project.
SO-3: an ability to communicate effectively with a range of audiences																		
4.a. Impart a precisely stated and strongly supported central message using appropriate, relevant, and compelling content to illustrate thoughtful command of the subject.	IPR	R			■	R						R			R	R/E	E	SE320: (TBD). BS373: GDP (IPR #2)
4.b. Exchange ideas as efficiently using a wide range of terminology and conventions common to the discipline of Systems Engineering.	IPR (Math 356)						R					R	R	R			E	Math356: TBD, info coming. SE336: Answer questions involving a single case

Figure 3: Excerpt from SE Curriculum Map Relating PC, Courses, and Assessment Artifacts.

Since multiple assessment artifacts may apply to a single PC, course directors were asked to aggregate the color-highlighted artifacts grouped by associated PC and listed in a matrix in the electronically reported Curriculum Review Letter. The result is a color-coded set of artifacts for each PC covered by the course, as depicted in the notional example of Figure 4. An overall summary evaluation of student performance for each PC is provided by the course director in the right most column of Figure 4 using the same green-yellow-red color-code.

SO Performance Criterion	Assessment Point 1	Assessment Point 2	Assessment Point 3	Overall Performance Criterion Assessment
1.a Frame and solve engineering problems using principles of engineering and science.	Reliability Homework	MX-ability Homework	Final Project	Satisfactory
2.a Create and refine functional system requirements from a stated need.	Req's & Feasibility Report & Conceptual Design Brief	System Description Document	Final Project Report	Concern
2.b Use a systematic process to develop and evaluate feasible candidate system solutions, identify alternatives, and select an appropriate solution.	GR-1 Grade	Final Project Sect's 1 & 2		Unsatisfactory

Figure 4: Notional Example of Course Director Evaluation Reporting by Performance Criteria.

The SE assessment manager further aggregates PC reports across courses using a similar methodology. Course and aggregated course overall performances deemed a *concern* or *unsatisfactory* are reviewed by the SE Committee after each semester in a SE program assessment review forum. Each yellow or red item is dispositioned for further monitoring or for action, depending upon recent performance history. Actions may include changes to instructional methods, changes in topic depth or emphasis in a course, changes in assessment artifacts, or other mitigating strategies. Item dispositions and action plans are documented in meeting minutes for follow-up at the subsequent semester's assessment review forum or with intermediate engagements, as warranted.

In addition to reviewing performance evaluation reports for PC, the assessment review forum analyzes comments from course directors regarding the applicability, effectiveness, and utility of assessment artifacts. All assessment architecture structures and processes are fair game for

comments and analysis within a continuing process of assessment program improvement. Course directors, teaching faculty, and administrators are encouraged to submit comments in a section of the Curriculum Review Letter for process improvement, including comments on individual course content and recommendations for changes in content, activities, assignments, or other operational and administrative factors. These comments, along with subsequent discussion, dispositioning, and actions are documented as one part of the SE Program's effort to comply with ABET Criterion 4, *Continuous Improvement* [1, p. 4]. This process is similar to that proposed by Crilly and Hartnett of the U.S. Coast Guard Academy for maintaining continuity of assessment in programs with moderate faculty turnover, a condition applying to the Air Force Academy [12]. Another example approach for addressing Criterion 4 as a design exercise has recently been offered by Fowler [13], and additional Criterion 4 considerations have been provided by Garry [14].

Results

Results of the Air Force Academy's revised assessment architecture, including the new ABET Criterion 3 Student Outcomes and associated new performance criteria, assessment artifacts, and evaluation methods, are very preliminary at the time of this writing. Only the first semester of new Curriculum Review Letters have been collected (fall 2017), and only this initial semester's assessment process review forum has convened.

However, the first semester revised assessment process proceeded smoothly. Curriculum Review Letters were collected for all fall semester SE course offerings, and a successful archiving of aggregated data was completed as planned. Several immediate improvements to assessment artifacts were identified in the post-semester assessment process review forum, and actions were assigned to respective course directors to implement the improvements in forward semesters.

Further, reviews of the overall assessment process by Course Directors, the SE Director, the SE Committee, the SE Board, local ABET reviewers, and other Academy engineering departments have been favorable. The SE Program has implemented a forum to assist other Air Force Academy engineering programs with their transition to the new ABET criteria and to coordinate assessment processes across engineering programs in preparation for the 2020 ABET reviews.

Improvements in the SE Program assessment architecture are clearly evident, and the goals established for the revision have been largely met:

- i. The SE Program is much better positioned to demonstrate its achievement of the new ABET Criterion 3 SOs through the enhanced traceability of assessment performance data to Performance Criteria and supported Student Outcomes.
- ii. The focused efforts of the SE assessment manager and SE Committee resulted in an expedited adoption of the new SOs and PC, promoting greater longitudinal assessment experience with these new guidelines prior to the next ABET review.

- iii. The merging and reformulating of ABET SOs facilitated consolidation of PC and reduced numbers of assessment artifacts. Combined with the careful adoption of PC language overlapping with institutional outcomes language, efficiency of data collection was improved significantly.
- iv. The reduced quantity of assessment artifacts combined with refinement of PC language to more specific and observable performance descriptions allowed the selection of higher quality and more specific artifacts for collection by Course Directors, better supporting the performance evaluation and traceability to each PC.
- v. The effort to revise the curriculum matrix identified and corrected several gaps and alignment errors in the legacy architecture.

In light of these preliminary results, the transition to the new ABET Criterion 3 Student Outcomes and the opportunity it presented for revising the SE Program architecture have been highly successful. The program faculty look forward to obtaining more complete results in the coming semesters, and particularly with the ultimate test – the outcome of the scheduled 2020 ABET review.

Roadmap and Recommendations for Engineering Academic Programs

The following recommendations and summary review of steps taken in the Air Force Academy's transition to new ABET Criterion 3 Student Outcomes and in the associated assessment architecture revision are provided for convenience to programs undertaking similar efforts.

1. Performance Criteria: Develop revised Performance Criteria to operationalize each new ABET Criterion 3 Student Outcome in a manner appropriate to the specific discipline.
 - a. For programs with historically successfully ABET-reviews, leverage legacy PC language and topics, as practicable.
 - b. Reference the mapping between expiring SOs and new SOs provided in this paper (Table 2) to help align legacy and revised PC with the new SOs structure.
 - c. Merge legacy PC language and concepts as required in the formulation of revised PC.
 - d. Refine or change PC language as necessary to ensure clearly defined, observable, and measureable student performance expectations.
 - e. Design revised PC language to overlap with the language of any assessment requirements external to the academic program, such as institutional level outcomes or performance criteria, as feasible.
2. Approval: Conduct organizational reviews and obtain organizational or administrative approval for the set of new SOs and PC, as required.
3. Assessment Artifacts: Review legacy assessment artifacts for suitability to support revised PC, and modify, change, or create new artifacts, as necessary.

- a. Review PC topic coverage by courses in the curriculum.
 - b. Map PC topic coverage (learning experience) to courses, including characterization of the depth or nature of coverage in each course. (See example curriculum matrix in this paper, Figure 3.)
 - c. Identify candidate assessment artifacts for each PC within courses providing a learning experience for the given PC.
 - i. Leverage legacy artifacts as practicable and suitable to new PC or to assessment architecture improvement goals.
 - ii. Seek new or additional artifacts, as needed, and distributed across the curriculum to ensure adequate evaluation coverage of the student population (100% coverage vs. large statistical sampling).
 - iii. Select or design specific graded events as assessment artifacts that directly evaluate the student expectations defined by PC, minimizing artifacts of coarse granularity such as semester average or course grade(s).
 - d. Conduct a review process to down-select candidate assessment artifacts to a manageable and ABET review-tenable subset that adequately evaluates the program student population.
 - e. Ensure alignment among the new assessment artifacts, individual course learning objectives, learning experiences, revised PCs, and institutional and ABET outcomes. [9, pp. 39-53]
4. Evaluation, Reporting, and Analysis: Revise or create a comprehensive evaluation, reporting, and analysis framework for consolidating and aggregating evaluation data into readily reviewable and interpretable form, including decision aids for when to take action for improvement. (See example in this paper.)
- a. Ensure that revised evaluation and reporting mechanisms are updated or designed to align with revised and new assessment artifacts.
 - b. Ensure that the assessment data aggregation procedures are consistent and promote valid aggregation across artifacts and courses in support of the associated PC.
 - c. Individual artifact data analyses and aggregated data product analyses should each include methods for dispositioning or recommending action for improvement.
 - d. Establish a schedule for regular periodic evaluation, reporting, and analysis.
5. Traceability: Document clear and logical traceability from the collected assessment artifacts to the Performance Criteria and Student Outcomes.
- a. Student performance reporting mechanisms and aggregated results should be explicitly linked to support for one or more PC.
 - b. Each PC should be clearly supported by the collected student performance data.
 - c. Each SO should be clearly supported by discipline-appropriate PC.

6. Continuing Improvement: Evaluate the legacy process for continuing assessment improvement in the context of the changes made to the assessment architecture, and adjust documentation, review, feedback, and action processes appropriately.
 - a. A process for assessment program review should be defined, documented, and undertaken with a specified frequency, typically aligned with the frequency of student evaluation, reporting, and analysis.
 - b. The student performance evaluation, reporting, and analysis process described in item 4 above may also include faculty feedback mechanisms contributing to a process of continuing improvement, per ABET Criterion 4.

Conclusions

The U.S. Air Force Academy Systems Engineering Program seized the opportunity of the recent change in ABET Criterion 3 Student Outcomes to undertake a holistic review and revision of its assessment architecture. The new ABET recommendations, along with recently obtained institutional feedback for improving the program's assessment processes, were used as input for the revision process. This holistic assessment architecture review and revision is a large and sweeping step in the process of continuing improvement of this academic program. The enhancements achieved through this effort will serve as a catalyst for further improvements to student learning experiences, course content, student evaluation methods, curriculum structure, institutional outcomes, and the ultimate preparation of engineering students to enter the workforce and graduate education. Of course, we are also confident that these assessment program improvements incorporating the new Student Outcomes will contribute to another successful ABET accreditation visit for our program in 2020.

As early adopters of the new ABET SOs and as assessment program architects, the Systems Engineering Program is leading the way for the other engineering programs at the Air Force Academy. These other programs will benefit from our well-documented revision process and the resulting new assessment architecture example. It is our hope that this effort will also benefit engineering programs across the globe at many other institutions. Our faculty and staff are pleased to extend an offer of assistance to other engineering programs as they revise their own assessment programs. The authors may be contacted at:

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