Quality Improvement with Automated Engineering Program Evaluations Using Performance Indicators Based on Bloom's 3 Domains

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Abstract— In this paper, we present examples of quality improvement efforts to enhance student learning in engineering education by employing a novel program evaluation methodology that automates ABET Student Outcomes (SOs) data measurement and analysis based on the classification of specific performance indicators per Bloom's 3 domains and their learning levels. The learning levels are further categorized based on a 3-Level Skills Grouping Methodology that groups together learning levels of related proficiency. Program evaluations use aggregate values of ABET SOs as an overall performance index. These values are calculated by assigning weights to measured specific performance indicators according to the Frequency-Hierarchy Weighting-Factors Scheme, which incorporates a hierarchy of measured skills, course levels in which they are measured, and counts of assessments implemented for their measurement. The number of assessments processed for measurement of performance indicators associated with the 3 categories of skills in multiple course levels is counted to calculate percentage learning distribution in the elementary, intermediate and advanced levels for the 3 learning domains. Learning distributions obtained for measured ABET SOs are compared to ideal models to verify standards of achievement for required types of skills, proficiency levels and align engineering curriculum delivery to attain highest levels of holistic learning.

Keywords— Outcomes Assessments; Bloom's Domains; Learning Domains; ABET; Student Outcomes; Skills; Learning Levels; Performance Indicators;

I. INTRODUCTION

Multiple research papers published by the National Institute of Learning Outcomes Assessment (NILOA) [11,12] and others [2,13,14] clearly state that in many higher education institutions, actual Continuous Quality Improvement (CQI) and accreditation efforts are minimally integrated and that, ideally, CQI instead of accreditation standards should be the prime driver for outcomes assessment [18]. The indispensable necessity of digital technology to automate and streamline outcomes assessment for accreditation is explained in many research papers [15,16,17,18,27,28,30]. State-of-the-art digital technology-based outcomes assessment systems would definitely help fulfill accreditation standards and achieve excellent CQI results. In this paper, we present the results of integration of fundamental concepts of the Outcomes Based Education (OBE) model with world-class best practices in outcomes assessment and web-based software EvalTools® 6, deployed with significant customizations.

The current format of measuring ABET, Engineering and Accreditation Commission (EAC), 11 SOs is definitely cumbersome for programs and institutions that utilize manual processes. The general advice provided to programs is to be very selective in using assessment for measuring these SOs to minimize overburdening faculty and program efforts for accreditation [18,35]. This is acceptable from the accreditation criteria fulfillment standpoint, but from the OBE model student-centered point of view, it does not facilitate CQI. These assessments tend to become summative and not formative, since educational assessment refers to all activities which provide information to be used as feedback to revise and improve instruction and learning strategies [1,10]. The learning outcomes data measured by most engineering institutions are rarely classified into all three learning domains of the revised Bloom's taxonomy [18,29] and their corresponding categories of the levels of learning. Generally, institutions classify courses of a program curriculum into three levels: introductory, reinforced, and mastery, with outcomes assessment data measured for the mastery level courses in order to streamline the documentation and effort needed for an effective program evaluation. This approach presents a major deficiency for CQI in a student-centered, OBE model, because performance information collected at just the mastery level is at the final phase of a typical quality cycle and occurs too late for implementation of remedial efforts.

Instead, student outcomes and performance criteria progressing from the elementary to advanced levels should be measured at the course level for all courses spanning the entire curriculum [18,31,32]. A holistic approach for a CQI model would require systematic measurement of specific Performance Indicators (PIs), in all 3 domains of learning of Bloom's taxonomy and their corresponding categories of learning levels, for all course levels of a given program's curriculum. Therefore, a digital PI bank containing a good number of well-defined specific PIs, classified per Bloom's 3 learning domains and learning levels, related to the ABET SOs, was developed at the Faculty of Engineering for the EE, CE, and ME programs. The specific PIs measured in all course levels have provided faculty members with precise information for course and program evaluation and subsequent improvement.

In the OBE model, assessments form the basis of learning, giving precise information for improvement, and thus are formative. Since assessment is an essential element of the educational process and is the basis of CQI, a novel technique has been implemented to estimate learning distribution achieved by an engineering program for a given term in Bloom's 3 domains and their learning levels. The learning levels in each domain are further categorized based on a 3-Level Skills Grouping Methodology that groups together learning levels of related proficiency to form 3 broad skills levels categories, namely: elementary, intermediate and advanced. Hence the number of assessments processed for the measurement of performance indicators associated with the 3 categories of skills in multiple course levels is counted. The assessments counts information is used to calculate percentage distribution of learning in the elementary, intermediate and advanced levels for the cognitive, affective and psychomotor domains of learning. Specifically, the ABET SOs coverage of Bloom's 3 domains has been studied in great detail. The percentage learning distribution individual and composite are available for specific and overall combined information related to the measured ABET SOs.

The complete assessment strategy for each measured ABET SO and estimation of program level competencies is provided in the 3 phase *SOs*, *PIs* and *learning domains* evaluation modules' term summary. The term summary contains detailed information on the type of assessments used, their course levels, counts, learning distributions and skill levels of the associated performance indicators measured and can be referred to in our previous work [18,28]. Any existing deficiencies in current assessment models for measured ABET SOs are identified through a detailed 3 phase program term review process conducted by faculty members. In particular, the programs' term review *learning domains* evaluation, which is presented in this paper, estimated learning distributions in Bloom's 3 domains and their 3 skills levels are compared with target ideal values to generate several CQI activities such as the modification or development of: teaching and learning activities; course outcomes; course topics; and assessments and associated PIs to correct the existing learning distribution deficiencies. This assessment methodology, *Hierarchy-Frequency Weighting-Factors Scheme* combined with digital technology, promotes the easy development and usage of formative assessments, making each phase of the course, curriculum delivery transparent to all stakeholders and provides precise information of where and why performance weaknesses exist for timely remedial actions. This implemented assessment methodology encourages faculty to use relevant information for real-time modifications. The generation of assessments and their mapping to specific PIs for measurement followed up with failure identification and remedial action is a total faculty affair, thereby creating the ideal situation for CQI in engineering education [18].

The alignment of student teaching and learning processes, by implementation of outcomes assessments to cover the 3 broad skills levels in all of the 3 Bloom's domains according to preset target percentage distribution levels presents an exciting, new frontier in holistic quality improvement methodologies to achieve the highest education standards for engineering programs world-wide. Therefore, the focus of this research is to present CQI efforts in engineering education using state-of-the-art, digital technology-based, automated outcomes assessment systems to implement proper alignment of program curriculum and course delivery according to ideal learning distributions scenarios required for various engineering specializations.

II. Engineering program evaluations

A. *Assessment Methodology*

The Faculty of Engineering at the Islamic University of Madinah has studied various options for developing its assessment methodology and systems [2,3,4,5,14,15,16,17,31] to establish actual CQI and not just to fulfill ABET accreditation requirements [35]. The following points summarize the essential elements chosen by the faculty to implement state-of-the-art assessment systems for achieving realistic CQI in engineering education [18]:

1. OBE assessment model
2. ABET, EAC outcomes assessment model employing Program Educational Objectives (PEOs), 11 EAC SOs and PIs to measure Course Outcomes (COs)
3. Measurement of outcomes information in all course levels of a program curriculum: introductory, reinforced and mastery.
4. The Faculty Course Assessment Report (FCAR) utilizing the Excellent, Adequate, Minimal, and Unsatisfactory (EAMU) performance vector methodology [24,25,26,27,28]
5. Well-defined performance criteria for course and program levels
6. A digital database of specific PIs [20] classified as per Bloom's revised 3 domains of learning and their associated levels (according to the *3-Level Skills Grouping Methodology*)
7. Unique Assessments mapping to one specific PI [28]
8. Scientific Constructive Alignment for designing assessments to obtain realistic outcomes data representing information for one specific PI per assessment [9,22,28]
9. Integration of direct, indirect, formative and summative outcomes assessments for course and program evaluations
10. Calculation of program and course level ABET SOs, COs data based upon weights assigned to various types of assessments, PIs and course levels
11. Course, program, and student level measurement and analysis of ABET SOs [28]
12. The *Program Term Review* module of EvalTools® 6 consisting of 3 parts a) *Learning Domains Evaluation* b) *PIs Evaluation* and c) *ABET SOs Evaluation* [18,28]
13. A student academic advising module related to measured outcomes data
14. Electronic integration of the Administrative Assistant System (AAS), the Learning Management System (LMS), the Outcomes Assessment System (OAS) and the Continuous Improvement Management System

(CIMS), facilitating faculty involvement for realistic CQI [23,28]

15. Electronic integration of Action Items (AIs) generated from program outcomes term reviews with the Faculty of Engineering standing committees' meetings, tasks, lists and overall CQI processes (CIMS feature)
16. Customized web-based software EvalTools® 6 facilitating all of the above [23]

B. COs, Specific PIs and Associated Assessments Classification Based upon the Revised Bloom's Taxonomy, 3 Domains and Their Learning Levels.

The design flow outlined in Section II.A adopted by the Faculty of Engineering for the creation of holistic learning outcomes and their performance indicators for all courses corresponding to introductory, reinforced and mastery levels spanning the curriculum has been mostly reported in [18]. But first, some of the key concepts needed, to lead into further details on the estimation of learning distribution based upon frequency counts of outcomes assessments used to measure specific PIs in the Bloom's 3 domains and their learning levels for multiple course levels, are given.

In past research [33], Bloom's learning levels in each domain were grouped based on their relation to the various teaching and learning strategies. With some adjustments, a new *3-Level Skills Grouping Methodology* was developed by the Faculty of Engineering, for each learning domain with a focus on grouping activities which are closely associated to a similar degree of skills complexity. Fig. 1 exhibits this new grouping [18].

As stated in several research papers [7,20,21,28,31,32], PIs should be specific in order to collect precise learning outcomes information related to various course topics and phases of a curriculum, while addressing multiple levels of proficiency of a measured skill. Fig. 2 indicates an ideal *learning level distribution model* for COs and PIs for the introductory, intermediate and mastery level courses. The measurement of outcomes and PIs designed following such an ideal distribution will result in a comprehensive database of learning outcome information, which will facilitate a thorough analysis of each phase of the learning process, and a comparatively easier mechanism for early detection of the root cause of student performance failures at any stage of a student's education [18, 28].

Ideally, all courses should measure the elementary, intermediate and advanced level skills with their COs, specific PIs and associated assessments. However, introductory level courses should measure a greater proportion of the elementary level skills with their COs, PIs and assessments. On the other hand, mastery level courses should measure more of the advanced, but fewer intermediate and elementary level skills [18]. The design of COs and their PIs was meticulously completed by using appropriate action verbs and subject content, thus rendering the COs, their associated PIs, and assessments at a specific skill level—elementary, intermediate or advanced. Fig. 3 shows an example from a civil engineering course, in which CO_2: *Describe the composition of soil and solve volume-mass relationship equations for soils*; and its associated specific PI_5_34: *Determine the physical properties of soil using given parameters*; measured by assessment, Mid Term Q9, are of similar skills complexity and therefore at the same level of learning. The corresponding category of learning is *intermediate-cognitive-applying.* Therefore COs would be measured by PIs and assessments strictly following the *3-Level Skills Grouping Methodology* [18].

Skills Level	Cognitive Domain (Bloom, 1856; Anderson & Krathwohl, 2001)	Affective Domain (Krathwohl, Bloom & Masia, 1973)	Psychomotor Domain (Simpson, 1972)
Elementary	1. Knowledge 2. Comprehension	1. Receiving phenomena 2. Responding to phenomena	1. Perception 2. Set 3. Guided response
Intermediate	3. Application 4. Analysis	3. Valuing	4. Mechanism 5. Complex overt response
Advanced	5. Evaluation 6. Creation	4. Organizing values into problems 5. Internalizing	6. Adaptation 7. Origination

Fig.1. 3-Level skills grouping methodology of Bloom's revised taxonomy

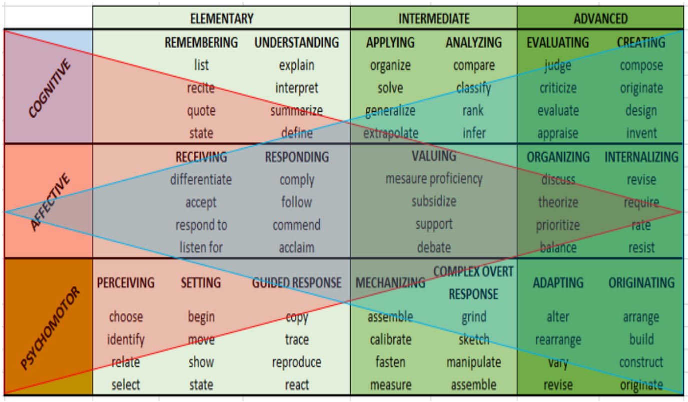


Fig.2. An ideal learning level distribution scenario for COs, PIs and associated assessments for introductory (indicated by shaded red triangle looking L to R) to mastery (indicated by a shaded blue triangle looking R to L) level courses

Details with illustration on examples of specific PIs EAMU vector calculation employing weighting factors is given in [18,25,28].

C. Hierarchy-Frequency Weighting-Factors Scheme for multiple learning and course levels

The philosophy behind the implementation of this Hierarchy-Frequency Weighting-Factor Scheme (HFWFS) for program learning domains evaluations is to consider a combination of two critical factors: (a) to implement a hierarchy of skills by giving prevalence to those assessments that measure skills of the highest order over others. For example, mastery-advanced level PIs will have a higher prevalence than those for the reinforced-advanced level; and (b) to consider the counts of assessments implemented in a certain learning level due to

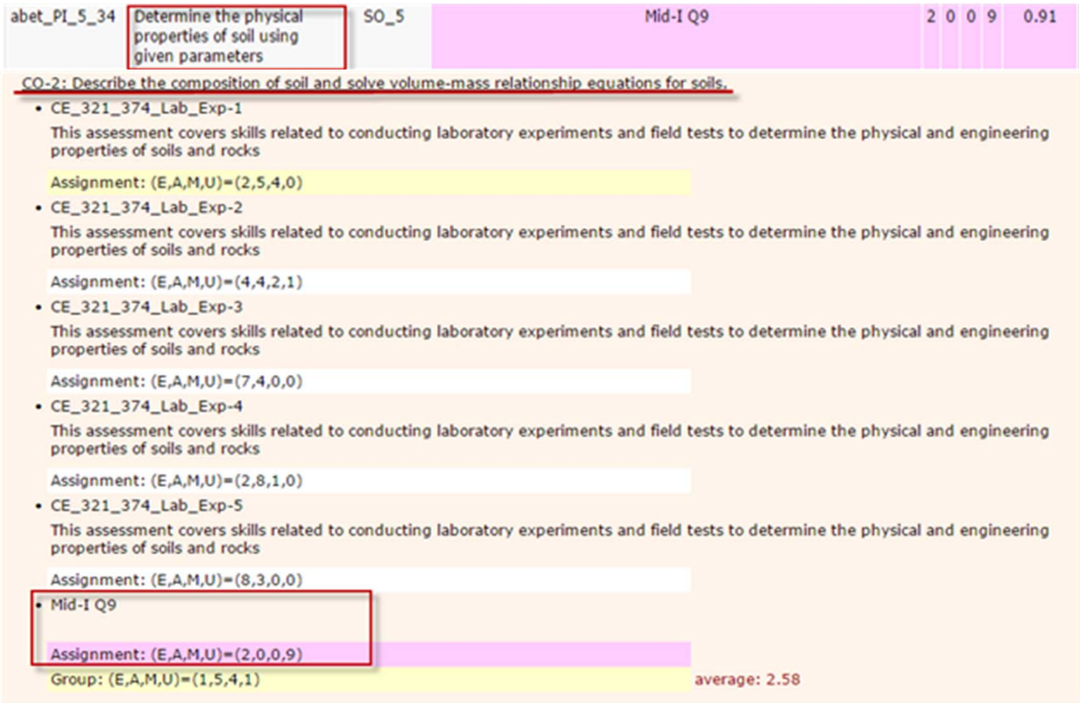


Fig. 3. Example of a civil engineering course showing CO_2, PI_5_34 and assessment Mid Term Q9 assigned to *intermediate-cognitive-applying* skill level based on the *3-Level Skills Grouping Methodology.*

Table 1: Weighting factors calculation for various learning levels of the reinforced and introductory courses for ABET SO 'a' program evaluation

ABET SO_1, SO 'a'	Course level- PI level	Counts(i) in term 361	%Learning Distribution [LD(i)]	% Progressive Distribution [PD(i)]	% Relative Distribution [RD(i)]	Weights WF(i) = LD(i) x RD(i)
Learning level (i)		DATA FROM EVALTOOLS	{counts(i)/total}×100	∑ LD(i)	{PD(i)}/Min{LD(i)}	{LD(i) × RD(i)}
1	REINFORCED-ADV	6	11.8	100	5.68	**67.05**
2	REINFORCED-INTER	14	27.5	88.2	5.01	**137.81**
3	REINFORCED-ELEM	9	17.6	60.7	3.45	**60.70**
4	INTRODUCTORY-ADV	0	0	43.1	2.45	**0.00**
5	INTRODUCTORY-INTER	13	25.5	43.1	2.45	**62.45**
6	INRTODUCTORY-ELEM	9	17.6	17.6	1.00	**17.60**
	TOTAL	51				

the fact that outcomes assessment is directly equivalent to learning. Table 1 shows the calculation of weighting factors for various learning levels of the reinforced and introductory courses, which are then applied to measured PIs in given course levels to compute the final program ABET SO 'a' value [18].

The detailed calculation for each column in Table 1 is reported in [18] and also shown below:

Learning Distribution % (LD)

Eqn. (1) shows the percentage of total assessments implemented in all courses for each learning level. Fig. 4 shows that for ABET SO 'a' (SO_1), 14 assessments out of 51 were implemented in reinforced-level courses measuring intermediate level PIs for all 3 domains composite. Assessments in this level accounted for 27.5% of learning.

$$LD(i) = \frac{count(i)}{Total\ count} \times 100 \qquad (1)$$

The *Progressive Distribution % (PD)*

Eqn. (2) calculates PD by summing *LD* values according to the hierarchy of the skills levels. Reinforced course and advanced skill levels are assigned the highest value in this case since mastery level courses were not offered in term 361.

$$PD(i) = \sum_{1}^{i} LD(i) \qquad (2)$$

The *Relative Distribution % (RD)*

Eqn. (3) calculates RD by dividing the *PD(i)* value with *LD(m):* the non-zero minimum value (learning level *'m'*) of the set of *LD* values corresponding to all the learning levels *1 to i.*

$$RD(i) = \frac{PD(i)}{Min - non - zero\ \{LD(1),\ LD(2), \ldots .LD(i)\}} \qquad (3)$$

The *Weighting Factors WF(i)* for the various measured learning levels given by Eqn. (4) for ABET SO 'a' (SO_1) are calculated by multiplying *LD(i)* with *RD(i).*

$$WF(i) = LD(i) \times RD(i) \qquad (4)$$

III. Continuous Improvement

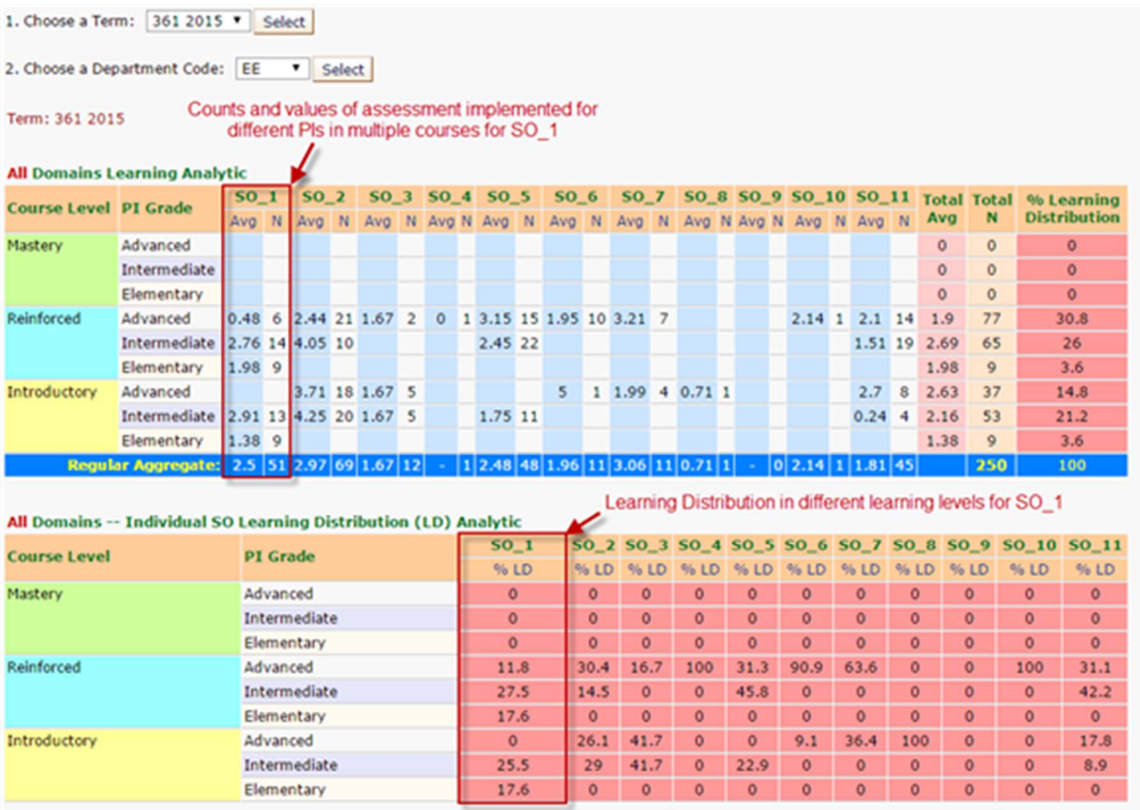
A. *Program-Level Learning Domains Evaluations*

Since assessments are equivalent to learning in the OBE model [34], the Faculty of Engineering has decided to consider the type of assessments, their frequency of implementation, and the learning levels of measured specific PIs in Bloom's 3 domains for courses and overall program evaluations. At the course level, the types of assessments are classified using the course formats chart to calculate their weighting factors [18,28], which are then applied using the *setup course portfolio* module of EvalTools® 6 [23]. The results can be seen in the FCAR and are used for course evaluations. The program level ABET SO evaluations employ a weighting scheme HFWFS, which considers the frequency of assessments implemented in courses for a given term to measure PIs related to specific learning levels of Bloom's domains [18]. This research focusses on some examples of CQI activities generated from the engineering program term review: *Learning Domains Evaluations*.

Fig. 4 shows the EE program term 361 composite learning domains evaluation data for their 11 ABET SOs. For each SO, the counts of total assessments and their aggregate average values are tabulated for each learning level [18].

Fig. 5 shows analytical results for the individual cognitive, affective and psychomotor— Bloom's domains of learning. The counts of assessments in various learning levels and their calculated values for all 11 ABET SOs are displayed for each learning domain. The ABET SO 'a' (SO_1) is highlighted for understanding. There is no data for the mastery level in Figs. 4 or 5 because the EE program is a new program, and hence, mastery level courses were not offered during term 361. Fig. 4 also shows the overall percentage learning distribution in each learning level for all the 11 ABET SOs. The details of how these entries are computed are explained in detail in our previous work [18]. Fig. 6 shows average values calculated on a 5.0 scale for the cognitive, affective and psychomotor domains, providing a good overall indication of how the program has performed in each learning domain. The pie chart indicates the EE program term 361 outcomes assessment activity percentage distribution in the 3 Bloom's learning domains [18].

A detailed term review report for each program was compiled with information on efforts for improvement targeting proper coverage of each ABET SO to achieve curriculum delivery according to the *Ideal Learning Distribution Model*. Fig. 7 shows portions of composite and individual ABET SOs learning domain evaluations review reports for the EE program for a specific term, in which the ABET SOs coverages of the Bloom's 3 domains and their learning levels, categorized as per the 3-Skills Level Methodology, are studied and discussed. On the left, a composite learning domains evaluation section is indicated, where the overall percentage distribution of learning in the 3 domains, ABET SOs coverages are analyzed and comments entered with possible suggestions for improvement of any deficiencies. On the right, portions of individual SO learning domain evaulations are shown with examples of deficiencies in certain ABET SOs such as "d" and "e". ABET SO_4 or "d", with just one assessment and a zero aggregate



Course Level	PI Grade	SO_1 Avg	SO_1 N	SO_2 Avg	SO_2 N	SO_3 Avg	SO_3 N	SO_4 Avg	SO_4 N	SO_5 Avg	SO_5 N	SO_6 Avg	SO_6 N	SO_7 Avg	SO_7 N	SO_8 Avg	SO_8 N	SO_9 Avg	SO_9 N	SO_10 Avg	SO_10 N	SO_11 Avg	SO_11 N	Total Avg	Total N	% Learning Distribution
Mastery	Advanced																							0	0	0
	Intermediate																							0	0	0
	Elementary																							0	0	0
Reinforced	Advanced	0.48	6	2.44	21	1.67	2	0	1	3.15	15	1.95	10	3.21	7					2.14	1	2.1	14	1.9	77	30.8
	Intermediate	2.76	14	4.05	10					2.45	22											1.51	19	2.69	65	26
	Elementary	1.98	9																					1.98	9	3.6
Introductory	Advanced			3.71	18	1.67	5					5	1	1.99	4	0.71	1					2.7	8	2.63	37	14.8
	Intermediate	2.91	13	4.25	20	1.67	5			1.75	11											0.24	4	2.16	53	21.2
	Elementary	1.38	9																					1.38	9	3.6
Regular Aggregate:		2.5	51	2.97	69	1.67	12	-	1	2.48	48	1.96	11	3.06	11	0.71	1	-	0	2.14	1	1.81	45		250	100

Course Level	PI Grade	SO_1 % LD	SO_2 % LD	SO_3 % LD	SO_4 % LD	SO_5 % LD	SO_6 % LD	SO_7 % LD	SO_8 % LD	SO_9 % LD	SO_10 % LD	SO_11 % LD
Mastery	Advanced	0	0	0	0	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	0	0	0	0	0
	Elementary	0	0	0	0	0	0	0	0	0	0	0
Reinforced	Advanced	11.8	30.4	16.7	100	31.3	90.9	63.6	0	0	100	31.1
	Intermediate	27.5	14.5	0	0	45.8	0	0	0	0	0	42.2
	Elementary	17.6	0	0	0	0	0	0	0	0	0	0
Introductory	Advanced	0	26.1	41.7	0	0	9.1	36.4	100	0	0	17.8
	Intermediate	25.5	29	41.7	0	22.9	0	0	0	0	0	8.9
	Elementary	17.6	0	0	0	0	0	0	0	0	0	0

Fig. 4. A given term learning domains evaluation for EE program showing all 3 domains' composite data with assessments counts and their aggregate average values for various learning levels and ABET SO 'a' highlighted.

Cognitive Domain Learning Analytic

Course Level	PI Grade	SO_1		SO_2		SO_3		SO_4		SO_5		SO_6		SO_7		SO_8		SO_9		SO_10		SO_11		Total Avg	Total N	% Learning Distribution
		Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N			
Mastery	Advanced																							0	0	0
	Intermediate																							0	0	0
	Elementary																							0	0	0
Reinforced	Advanced	0.48	6							3.15	15											2.33	10	1.99	31	19.9
	Intermediate	2.76	14							2.45	22											1.51	19	2.24	55	35.3
	Elementary	1.98	9																					1.98	9	5.8
Introductory	Advanced			3.57	7	1.67	5															2.78	7	2.67	19	12.2
	Intermediate	2.91	13			1.67	5			1.75	11											0.24	4	1.64	33	21.2
	Elementary	1.38	9																					1.38	9	5.8
																								2.05	156	100.2

Affective Domain Learning Analytic

Course Level	PI Grade	SO_1		SO_2		SO_3		SO_4		SO_5		SO_6		SO_7		SO_8		SO_9		SO_10		SO_11		Total Avg	Total N	% Learning Distribution
		Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N			
Mastery	Advanced																							0	0	0
	Intermediate																							0	0	0
	Elementary																							0	0	0
Reinforced	Advanced							0	1			1.95	10	3.21	7					2.14	1			1.83	19	76
	Intermediate																							0	0	0
	Elementary																							0	0	0
Introductory	Advanced											5	1	1.99	4	0.71	1							2.57	6	24
	Intermediate																							0	0	0
	Elementary																							0	0	0
																								2.01	25	100

Psychomotor Domain Learning Analytic

Course Level	PI Grade	SO_1		SO_2		SO_3		SO_4		SO_5		SO_6		SO_7		SO_8		SO_9		SO_10		SO_11		Total Avg	Total N	% Learning Distribution
		Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N	Avg	N			
Mastery	Advanced																							0	0	0
	Intermediate																							0	0	0
	Elementary																							0	0	0
Reinforced	Advanced			2.44	21	1.67	2															0.95	4	1.69	27	39.1
	Intermediate			4.05	10																			4.05	10	14.5
	Elementary																							0	0	0
Introductory	Advanced			3.81	11																	2.62	1	3.22	12	17.4
	Intermediate			4.25	20																			4.25	20	29
	Elementary																							0	0	0
																								3.04	69	100

Fig. 5. Learning domains evaluation for EE program term 361 showing assessment counts and values for the individual cognitive, affective and psychomotor domains

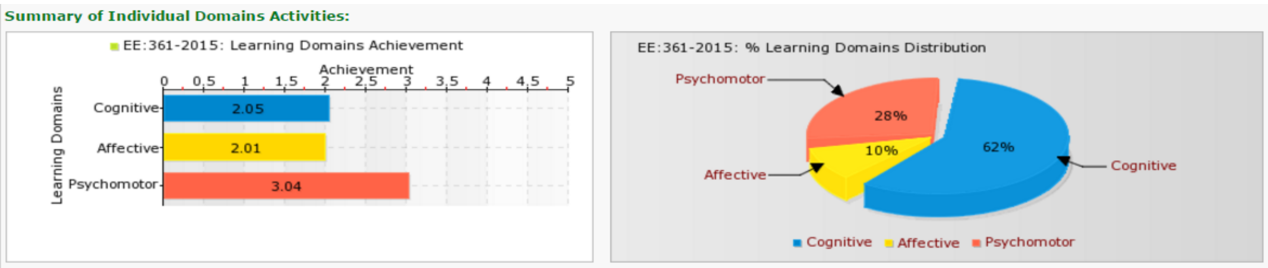


Fig. 6. Learning domains evaluation histogram and pie chart for EE program term 361 showing the percentage distribution of assessment activities in Bloom's 3 learning domains

value as shown in Fig. 5, deals with team work skills related mostly to the affective domain. The assessment for this SO was not properly implemented and required the creation of specific instruments, PIs, rubrics and strategies targeting select capstone courses with significant elements of teamwork related to design projects. The other example, ABET SO_5 or "e", dealing with problem solving as shown in Fig. 4, had no assessments for the introductory and reinforced courses, for measurement of elementary skills in either of the 3 domains. Problem solving in the EE curriculum primarily involves cognitive activities such as application, analysis or evaluation and some psychomotor activities such as mechanism, complex overt response or adaption corresponding to the intermediate and advanced levels. The review comments therefore indicate difficulty in measuring the elementary level skills for ABET SO_5 or "e" in the past term.

In general, for all programs, ABET outcomes "b" and "c" corresponding to various aspects of conducting experiments and design work per realistic constraints cover all 3 learning domains. Several PIs were developed for the experimental and design work to cover all 3 domains. Special instruments containing PIs, rubrics and assessment strategies with a focus on analysis of final design to fulfill realistic constraints are in the developmental phase for measurement of various skills levels in all 3 learning domains in the senior design courses. In all programs, affective domain ABET SOs like "f," "h," "i," or "j," corresponding to professional ethics, impact of engineering solutions on the environment, lifelong learning, contemporary issues etc., were usually covered by the intermediate and advanced level skills dealing with valuing, organizing values into priorities, or internalizing. In the past term, affective domain, elementary skills were not measured for these SOs.

All skills levels in the affective and psychomotor domains are difficult to measure for an engineering curriculum since they require specific, complex instruments with significant amounts of resources allocation for implementation of valid assessment processes. An important observation is that the comprehensive coverage of all the Bloom's learning levels for

Action	Review Date
COMPOSITE LEARNING DOMAINS EVALUATION: All the domains of learning have reached appropriate levels of coverage. However, the affective domain assessments can increase to 20% in the future. SO1,2,3,5 and 11 were covered for the cognitive domain. SO4,6,7 and 10 were covered for the affective domain. However, SO4 needs proper assessment with a course containing a capstone design project for measurement. The program faculty shall endeavor to develop and utilize additional assessments to cover the affective domain in 300 and 400 level courses for term 362. SOs 3,4,6,9,10 will also be targeted for measurement in the future terms. Psychomotor has percentage distribution of 28% in term 361 due to several lab courses and practical activities. SO2, SO3 and SO11 have been covered in the psychomotor domain cognitive has coverage of 64% with ABET SO1, SO2, SO3, SO5, SO11 have been covered for the cognitive domain.	2016-03-01

INDIVIDUAL SO LEARNING DOMAINS EVALUATIONS:

SO_4:

Team work skills were not measured in 361 since the EE program intends to use capstone design courses for appropriate measurement of team work skills.

A new team work measurement instrument has been recently developed and available for implementation.

SO_5:

Introductory level courses have not measured the advanced and elementary skills.

Introductory level courses in the EE program are focused more on the application and analysis level

Reinforced level course have no elementary skills assessments since much of the activity is related to application and analysis of basic principles in problem solving.

Fig. 7. Portions of EE program learning domains evaluation reports for alignment of course and curriculum delivery as per Ideal Learning Distribution Model; column on right shows 3-skills levels coverage deficiencies in ABET SOs 4 ("d") and 5 ("e") extracted from report for all 11 SOs

each ABET SO is not a trivial process and requires multi-term measurement and analysis of all courses and relevant assessments processed in a complete cycle of any engineering curriculum. Specifically, elementary skills involve activities that deal with: remembering, understanding in the cognitive domain which are more relevant for the ABET SO "a": *Application of the principles of math, science and engineering*; receiving, responding in the affective domain corresponding to students' responses, emotional attitudes, interests to elementary phases of teaching and learning that do not involve critical thinking; and perceiving, setting or guided response in the psychomotor domain corresponding to students' natural and learned set responses to stimuli and capability to immediately replicate teacher's instructions. Introductory drawing courses in CE program covered aspects of guided response skills in the psychomotor domain. Since many of Bloom's affective and psychomotor elementary skills may not be within the scope or focus of measurement for most engineering specializations, it could be recommended, to develop alternate learning levels models for the realistic measurement of skills, for the affective and psychomotor domains in engineering education.

B. *Course-Level Learning Distribution Alignment*

Fig. 8 shows a course delivery alignment example, where an introductory level course, Electronics, EE_212_1487, in a

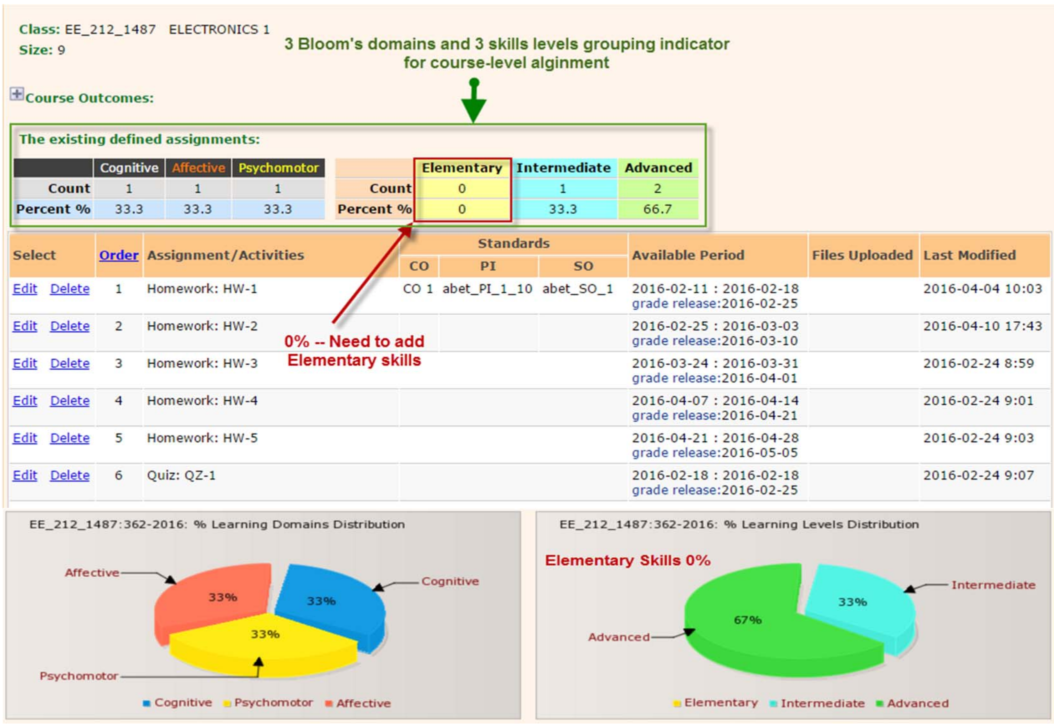


Fig. 8. Example of course-level learning domains realtime evaluation showing elementary skills not covered at a certain phase of course delivery

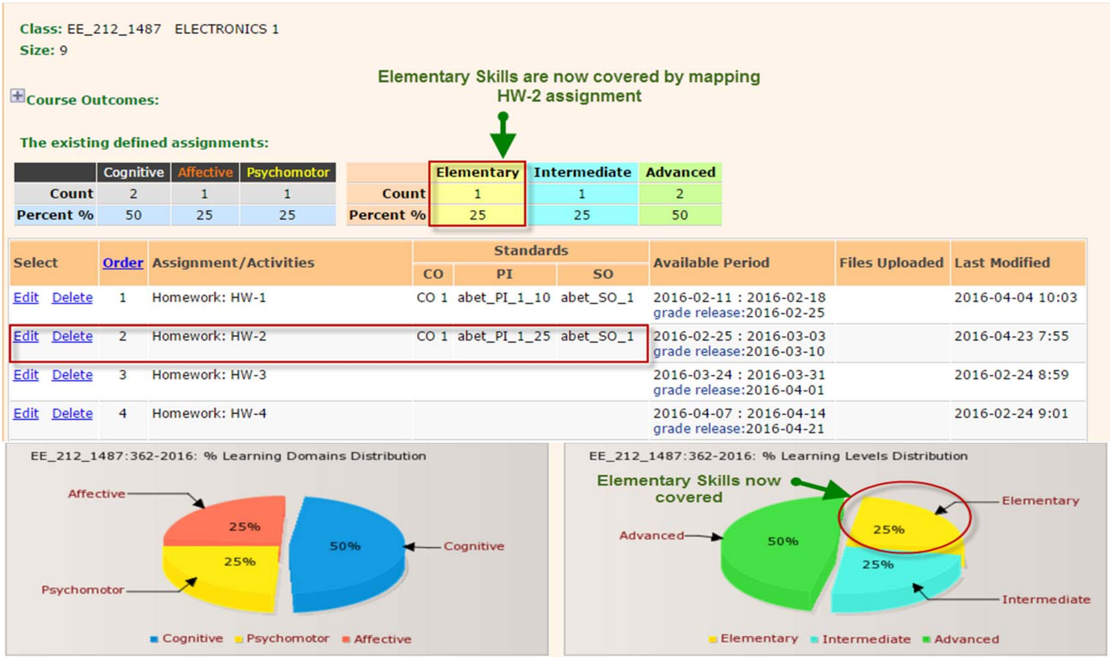


Fig. 9. Course-level learning domains realtime evaluation showing deficiency in measurement of elementary skills overcome by mapping existing assignment HW2 to elementary ABET_PI_1_25.

realtime, course-level learning domains evaluation, did not cover elementary skills with its existing set of assignments.

To cover elementary skills, either existing assignments need to be identified and mapped to elementary skills PIs for measurement or additional assessments, PIs need to be created. In this case, as indicated in Fig. 9, an existing assignment, HW2, was relevant, and mapped to elementary skills corresponding to ABET_PI_1_25 (cognitive-understanding): *Describe the characteristics of electrical circuit components and materials, such as resistance, inductance, capacitance, conductors, semiconductors and dielectrics;* to achieve realtime comprehensive coverage of learning disributions. For another EE course, Signals and Systems, which was just covering the cognitive domain, advanced and intermediate skills, additional COs, PIs were introduced to cover elementary and psychomotor domain skills to achieve holistic learning distributions. A course outcome, CO1: *Describe continuous-time and discrete-time signals and perform various operations on signals like transformation of independent variable;* was introduced and mapped to ABET_PI_1_59 (cognitive-understanding): *Explain signals and perform various time domain operations on signals;* using existing assignment HW1 to cover the required elementary skills. Another course outcome, CO2: *Represent CT and DT signals in complex exponential and sinusoidal form;* was added to cover missing psychomotor skills measured by ABET_PI_1_80 (psychomotor-complex overt response): *Represent diagrammatically, complex exponential and sinusoidal forms of continuous-time and discrete-time signals;* using existing assignments QZ-1 and Mid Term Exam-1 Q1.

In summary, a large number of changes were introduced at the Faculty of Engineering in every aspect of curriculum delivery for all programs, EE, ME or CE, and it was beyond the scope of this paper to list all the details of modifications. The focus of this paper was to therefore show that a combination of analytical data from program-level ABET SOs and course-level COs learning domains evaluations facilitates planned plus realtime alignment of course topics, course outcomes, assessments, PIs, rubrics, teaching and learning strategies to attain ideal learning distributions in Bloom's 3 domains and therefore highest levels of CQI in engineering education.

IV. CONCLUSION

This paper presents a novel outcomes assessment methodology using customizations in web-based software EvalTools® 6 modules to analyze program learning distribution information in Bloom's 3 domains based on the counts of assessments processed in multiple course and skills levels of an engineering curriculum. This learning distributions information provides a wealth of detail to engineering programs regarding any deficiencies in their current ABET SOs assessment plans and helps steer any future or realtime modifications to achieve an optimum distribution of coverages in the various learning domains and their learning levels. These CQI activities would result in the required alignment of program, course learning outcomes, associated PIs with assessments, teaching and learning strategies to produce necessary skill levels and learning domain coverages specific to the various engineering specializations. Engineering programs employing this approach would generate and classify COs, their PIs using the 3 levels skills grouping method in a relatively easier process and make outcomes assessments the focus for effective pedagogy as required by an ideal OBE model while implementing constructive alignment throughout the curriculum delivery process. Application of this methodology and digital systems would help develop holistic curriculum delivery processes with learning outcomes forming the fundamental ingredients of every aspect of engineering education to produce quality graduates for the industry with necessary skills levels related not only to the cognitive but also to the affective and psychomotor domains.

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