IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received March 4, 2021, accepted March 15, 2021, date of publication March 17, 2021, date of current version March 30, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3066921

Impact Evaluations of Engineering Programs Using ABET Student Outcomes

WAJID HUSSAIN[1,2], (Senior Member, IEEE), WILLIAM G. SPADY[2], SOHAIB ZIA KHAN[1], BILAL A. KHAWAJA[1], (Senior Member, IEEE), TAYYAB NAQASH[1], AND LINDSEY CONNER[3]

[1]Faculty of Engineering, Islamic University of Madinah, Medina 42351, Saudi Arabia
[2]International Network for Outcome Based Education (IN4OBE), Naperville, IL 60540, USA
[3]College of Education, Psychology and Social Work, Flinders University, Adelaide, SA 5042, Australia

Corresponding author: Wajid Hussain (wajidmiami@gmail.com)

ABSTRACT Engineering programs worldwide collect and report student learning outcomes data to conduct program evaluations for quality assurance and accreditation purposes. Accreditation agencies such as ABET typically mandate that at least two years of program evaluation data be provided and for institutions to show how this data has been used for continuous quality improvement. Engineering programs rarely evaluate interventions using multi-term student outcomes information over several years, since this quantitative data generally lacks accuracy and statistical power. The quality of outcomes data is affected by obsolete assessment methods and lack of digital access and technical analysis. In this study, we present essential elements of an authentic outcome based assessment model that used web-based software and embedded assessment technology to collect and report accurate cohort outcomes for credible multi-term evaluations. A non-experimental approach employing regression analyses were used to identify trends in student outcomes and evaluate the impact for three engineering programs. Detailed rubrics provide criteria to accurately classify multi-year student outcomes. The findings of this study present practical steps for engineering programs to effectively collect and report accurate cohort outcomes data and perform credible evaluations of program interventions based on multi-year outcomes data.

INDEX TERMS ABET, outcomes, assessment, OBE, performance indicators, continuous quality improvement (CQI), program evaluation.

I. INTRODUCTION

Engineering accreditation standards as defined by the International Engineering Alliance's (IEA) Washington Accord [1] are derived from the philosophy, paradigm and principles of the Outcome Based Education (OBE) model [2]–[10]. As per Spady, the premise of OBE is that every component of an educational system should be based on essential outcomes [2]–[6]. Students should achieve the essential or culminating outcomes after every learning experience. All aspects of learning such as instructional strategy, assessments, evaluations, feedback, and advising should help students attain the intended outcomes. This model helps engineering programs adopt a student centered approach by focusing on attainment of culminating outcomes of student learning experiences rather than the quality of the offered curriculum [2]–[6]. Additionally, accreditation bodies require that engineering programs maintain well established and sustainable CQI processes based on outcomes [1], [11]–[16]. An exhaustive review of literature shows that collecting and reporting massive amounts of Continuous Quality Improvement (CQI) data for accreditation audits using manual methods is one of the most challenging tasks for engineering programs [19], [21]–[24], [26], [30], [31], [34]–[41], [44], [45], [54], [76]. Specifically, to fulfill international quality standards of the Accreditation Board of Engineering and Technology (ABET), engineering programs are required to maintain CQI processes based on an OBE model and prepare self-study reports with multiple years of evidentiary data for review in an audit visit. ABET requires engineering programs to fulfill 9 accreditation criteria. The most significant criteria with respect to CQI are the *Program Educational Objectives* (PEOs), *Student Outcomes* (SOs), *Program Criteria* and *Continuous Improvement* [11].

Most programs in the US and internationally, state that the most difficult criteria to fulfill for ABET accreditation was

The associate editor coordinating the review of this manuscript and approving it for publication was Binit Lukose.

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 License.
For more information, see https://creativecommons.org/licenses/by-nc-nd/4.0/

criteria 4, for CQI [19], [21]–[24], [26], [30], [31], [34]–[41], [44], [45], [54], [76]. The CQI criteria 4 requires programs to track quality improvement resulting from corrective actions for students' performance failures extracted from assessment and evaluation of outcomes at the course and program level. ABET's evaluators require programs to implement 6 years of quality cycles with at least 2 years of well documented data as display material during audit visits. The general advice provided to programs is to be very selective in using assessment for measuring ABET SOs to minimize overburdening faculty and program efforts for accreditation [11], [36], [40], [45], [56]. 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 [27], [28]. Programs using manual CQI systems tend to consider relatively small student sample sizes for assessment of SOs data which consequently fulfill minimal accreditation requirements [22], [24], [26], [28], [29], [36], [39], [40], [43], [45], [56], [60]–[63], [72], [76]. Additionally, most engineering programs rarely classify learning outcomes data in all the three learning domains with corresponding learning evels of the revised Bloom's taxonomy [7], [20], [23], [24], [26], [30], [31], [40], [48], [52]–[54], [58]. Courses within a program are]generally classified into three levels: *Introductory*, *Reinforced*, and *Mastery*, with outcomes data assessed at *Mastery Level* for streamlining the documentation and reporting efforts needed for effective program evaluations. However, collecting performance information at just the *Mastery* level represents the final phase of a typical quality cycle and is too late for remediation. Data sampling following such an approach presents a major deficiency for CQI in student-centered OBE models. In fact, SOs and performance criteria progressing from the elementary to advanced levels should be assessed at the course level for all courses spanning the entire curriculum [26], [30], [31], [36], [39], [41], [56]. A holistic approach for a CQI model would require a systematic measurement of Performance Indicators (PIs) in all three of Bloom's domains of learning and their corresponding learning levels for all course levels of a program. Manual CQI models have been increasingly cited in literature as being deficient with several issues such as deficient standards of language of learning outcomes statements, generic and vague performance criteria, lack of use of accurate topic specific analytic rubrics, lack of reliable and valid assessment and evaluation criteria, random or ad hoc sampling of outcomes information, lack of proper alignment of learning activities with outcomes, inability to achieve comprehensive coverage of Bloom's three domains of learning, lengthy and impractical quality cycles, inability to implement real-time learning improvements in enrolled cohorts etc. [23], [29], [39], [40], [42]–[45], [48], [53], [54], [56] [58], [61], [62], [76].

Engineering programs can adopt an authentic OBE philosophy for implementing quality learning outcome statements, specific performance criteria and analytic rubrics that are all aligned to assess student knowledge and skills in all three domains and their learning levels. Only after implementing a coherent learning model that aligns assessment to learning outcomes, can data collection be effective for evaluating impact of programs. Onwuegbuzie and Hitchcock (2017) emphasized the need for rigorous evaluations of impact of programs around the world so that trustworthy evidence of change can be used for future decision making [49]. According to them, a vast majority of impact evaluations across various fields including education, have involved the use of quantitative experimental, quasi-experimental and non-experimental methods [49]. The impact evaluations based on data collected for learning outcome assessments and accreditation requirements would be non-experimental since the use of control groups in educational settings dealing with delivery of curriculum is an impractical exercise which could not be managed institutionally. However, engineering programs can conduct non-experimental impact evaluations which use *difference in differences models* with actual comparison groups or *regression models* that do not explicitly use comparison groups. Manual CQI systems that collect continuous data by employing authentic OBE and assessment methodology are required to incorporate appropriate sample sizes in their study design to achieve satisfactory statistical power for data related to all the ABET SOs.

Impact evaluations estimate the effects on outcomes by comparing a sample from intervention and control or comparison groups. It is more likely that a larger sample would be a more accurate representation of the population from which it is taken. The probability of an evaluation identifying a significant impact when there is actually one, is called statistical power. The impact of interventions is mostly evaluated using cluster designs in which data is collected from several subunits. The impact of interventions may be assigned to institutions, but outcomes are assessed individual students and for cohorts [51], [72]. This approach has significant implications for sampling methods and sizes, which are often not adequately recognized or calculated in impact evaluation studies [73]. In the case of program evaluations based on student outcomes, for achieving enhanced statistical power, the program would need to sample a relatively large number of students from courses spanning all levels of the curriculum. The statistical power of the design is determined by the number of clusters in the study rather than the number of treated units. This means that the example would need a reasonably large number of contributing courses. However, cluster designs require larger sample size than simple random sampling to have equivalent statistical power. Power is higher the more heterogeneous the units are within a cluster [72].

For engineering programs employing manual CQI systems, power calculations need to be performed to determine the sample size for a study that is sufficient for finding statistically significant intervention effects. If the sample size is too small then the study would be "underpowered," with the risk that the evaluation would not find a significant impact even though there was one. It would be higly probable to have implications for false positive or negative results with too small of an outcomes assessment sample. Too large a sample would mean that the study would require larger than affordable effort and resources for data collection and reporting. Apparently, small samples can save time and financial resources, but this comes at the cost of reducing accuracy when finding significant intervention effects. In the case of underpowered evaluations, they may offer little or no useful information since it would be impossible to acurrately determine whether an intervention is actually working or the findings do not indicate any impact due to the study being underpowered [51], [72].

A succinct statement of research findings made by the Evaluation Gap Working Group (2006) clearly sums up a general state of current program interventions, "*Of the hundreds of evaluation studies conducted in recent years, only a tiny handful were designed in a manner that makes it possible to identify program impact*" (p. 17) [50]. Engineering program evaluations that utilize manual CQI systems, despite implementing some authentic OBE and assessment practices, are commonly underpowered for the following reasons [56]:

a) Program chairs or assessment teams simply select what they think is an appropriate sample size generally from a final phase of an education process without performing appropriate power calculations.
b) Clustering of interventions is not considered, which means multiple cohorts for various sections of the same or multiple course(s) are not sampled.
c) Lack of consideration of the degree of homogeneity or heterogeneity of the student population within each course or multi-course sample(s).
d) The outcomes data is not evaluated over a realistic period of time (multiple years) to actually assess the full effect of a program intervention but concluded prematurely.
e) Outcomes data is not sampled from all three domains of Bloom's learning model.
f) Sample sizes are variant and insufficient with some SOs assessments using appropriate sizes and others being too small.
g) The study may be powered sufficiently to estimate the average treatment effect, but not for any subgroup analysis. So there would be no heterogeneity in impact of outcomes data between seniors or freshmen, mastery courses or introductory, higher order or lower order skills, formative or summative assessments etc.
h) There is attrition in the study design, such that data are actually collected from a smaller sample than originally planned.

Paper-free web-based digital systems with user friendly interfaces can encourage faculty participation and employ embedded assessment technology that can solve many issues related to achieving desired statistical power for accurate impact evaluations. The indispensable necessity of digital solutions to automate and streamline outcomes assessment for accreditation is explained in many research papers [22], [26], [34]–[39], [44], [56]. State-of-the-art digital technology-based outcomes assessment systems would definitely help fulfill accreditation standards and achieve excellent CQI results as well. Several digital solutions have been proposed recently to alleviate the aforementioned issues with manual CQI systems [21], [22], [26], [34]–[41], [45]–[47], [54], [56], [72], [76]. Considering the latest ground breaking developments related to digital automation of CQI processes, several accreditation bodies such as ABET have incorporated special language in their accreditation policy to accommodate engineering programs that choose to maintain digital display materials for accreditation audits [11].

In this study, we present essential elements of an authentic outcome based assessment model implemented using web-based software EvalTools® [45], [47] and embedded assessment technology employing the Faculty Course Assessment Report (FCAR) and Performance Vector Table (PVT) methodology [40], [45], [68] to effectively collect and report accurate cohort outcomes data scientifically aggregated from all courses in a program for credible multi-term evaluations. A non-experimental approach employing linear regression methods is used to perform SOs trend analyses for Electrical Engineering (EE), Mechanical Engineering (ME) and Civil Engineering (CE) programs' impact evaluations at the Islamic University of Madinah. Detailed rubrics provide qualifying criteria to accurately classify multi-year SOs performances. The trend analyses enable credible impact evaluations for program interventions. The findings of this study present implications for practical steps for engineering programs to collect and report accurate cohort outcomes data effectively and perform credible evaluations of program interventions based on multi-year outcomes data.

II. PURPOSE OF STUDY

The driving force behind this research is to examine the benefits and limitations of application of essential theory of the authentic OBE model for the implementation of a holistic and comprehensive educational process that maximizes opportunities for the attainment of successful student learning. The objective is to conduct effective non-experimental impact evaluations using multi-year (2014-20) SOs trend analyses for EE, ME and CE program interventions employing state of the art Integrated Quality Management Systems (IQMS).

In particular, the researchers sought to answer the following research questions:

1. What are some common issues that affect the statistical power of quantitative outcomes data collected by many engineering programs?

2. What are some essential elements of best assessment practice and available automated digital technology that help attain valid and reliable outcomes data?

3. Can multi-year SOs data be used to conduct credible impact evaluations? If so, what are some essential

requirements to ensure the validity and reliability, and statistical power of SOs data?

III. RESEARCH FRAMEWORK

A. METHODOLOGY

This research involves an OBE theory based qualitative analysis of SOs data for manual CQI systems obtained through a selective literature review covering accreditation topics in relevant engineering education and education psychology research literature. An indepth description of the theoretical, conceptual and practical frameworks are followed with quality management details of the PDCA quality cycle Q_5 regarding multi-term ABET SOs (a-k) reviews. Results of the study include review of various sections of detailed executive summary reports regarding SOs attainment, PI evaluations, trend plots and program committee actions. Finally, we apply a non-experimental approach employing regression methods to perform multi-year (2014-18) trend analyses of ABET SOs (a-k) for the EE, ME and CE programs' impact evaluations at the Islamic University of Madinah. Detailed rubrics provide qualifying criteria to accurately classify multi-year SOs performances. Results of trend analyses following this approach enable credible impact evaluations for program interventions without the explicit use of comparison groups. We show how the process flow for PDCA quality cycle Q_5 is applied to summarized results of SOs (a-k) trend analyses for the three programs thereby helping program committees to arrive at final review decisions for their respective impact evaluations The findings of this study present practical steps for engineering programs to collect and report accurate cohort outcomes data effectively and perform credible evaluations of program interventions based on multi-year ABET SOs data.The application of essential elements of authentic OBE assessment methdology and digital embedded assessment technology provide practical gudelines for the automation of collection and reporting of multi-term ABET SOs (a-k) data for quality assurance and accreditation purposes. Using regression methods to analyze valid and reliable multi-year SOs data with high statistical power can enable credible impact evaluations.

B. PARTICIPANTS

The non-experimental impact evaluation of the Faculty of Engineering EE, CE and ME programs from 2014 to 2018 involved 39 faculty members and 672 students from multiple cohorts of the 4-year bachelor of science programs.

C. SOs DATA FOR MANUAL CQI SYSTEMS– A QUALITATIVE ANALYSIS

A selective literature review related to engineering program evaluations for accreditation was completed to conduct an effective OBE theory based qualitative analysis of SOs data for manual CQI systems. We primarily considered research on accreditation topics in popular engineering education and educational psychology journals and conference proceedings spanning the last 15 years. The results of the literature review were parsed using an OBE theory based qualitative analysis of CQI systems to yield the summary below:

TABLE 1. Qualitative analysis of SOs data for manual CQI systems.

VALIDITY & RELIABILITY	Several fundamental aspects of authentic OBE theory are either not targeted nor achieved [17,21,23-24,26,30-31,41,45,48,52,56]
	Learning models are not understood and applied comprehensively as a basis for CQI efforts [4,20,41,48,52,56]
	Alignment of actual learning activities and language of Course Outcomes (COs) and associated PIs are deficient [4,20,30-31,41,48,52-54,56]
	PIs are used to assess SOs and are mostly generic thereby lack the required specificity for valid and reliable assessment and evaluation [20,23,25-26,28,30-31,36,39-41,45,48,56,57,58]
	Most rubrics are generic and vague using simplistic language and lack technical details to accurately assess several hundred complex engineering activities [20,23,26,41,56,57,58]
	Generic rubrics are applied by independent raters to score past course portfolios [36,40-41,45,56,59,61,63]
STATISTICAL POWER	Assessment plans mostly measure cognitive learning while learning in the psychomotor and affective domains is not assessed [7,20,23-24,26,30-31,39-41,45,48,52,54,56-58]
	Most quality systems do not collect, document and report outcomes and CQI information for all enrolled students because the sample size is too large to handle manually [6,21,24,26,28,30-31,36,39-43,50]
	Most program evaluations incorporate ad hoc or random sampling representing a small set of student learning activity [22,24,26,30-31,36,39-40,43,45,56,59-63]
	Course evaluations do not aggregate outcomes results from various types of assessments using appropriate weightage [24,26,39,45,48,56]
	Program evaluations do not aggregate multiple course and skill levels by applying appropriate weightage [22,26,37,39-40,45,48,53,56]

IV. THEORETICAL, CONCEPTUAL AND PRACTICAL FRAMEWORKS

The philosophy, paradigm, premises and principles of Authentic OBE form the basis for theoretical frameworks that lead to the development of crucial models which act as the foundation of the IQMS implemented at the Faculty of Engineering. Several essential concepts are then induced from OBE theory, assessment best practices and ABET criterion 4, on continuous improvement. Several viable techniques and methods based on this conceptual framework are then constructed as a practical framework of automation tools, modules and digital features of a state of the art web-based software EvalTools® [47].

A. THEORETICAL FRAMEWORK

ABET and Washington Accord advocate the OBE model, that uses culminating learning outcomes, as their gold standard for evaluating the quality of engineering programs worldwide [11], [16]. Engineering programs seeking accreditation should ensure that all components of the education process such as learning activities, assessments, evaluations, feedback, and advising help students foster and attain the intended outcomes. The essential elements of OBE were developed at the High Success Network [2], [3] and expounded in more detail in a recent publication [4]. The paradigm, premises, philosophy and four power principles of the OBE model [4]–[6] are used as theoretical frameworks to implement and evaluate the IQMS at the Faculty of Engineering [26], [36], [40], [41], [56], [76]. In essence, culminating, enabling and discreet learning outcomes should be the basis of all components of an educational system for aiding all students to successfully attain the intended knowledge and skills as prescribed by international standards of engineering education and curriculum [11], [56], [76].

B. CONCEPTUAL FRAMEWORK – MODELS

1) LEARNING MODELS

Learning is a complex process that requires careful planning to achieve the desired outcomes. Models of teaching and learning inform educators and researchers regarding the education processes, their inputs, outputs, variables, the causal interconnections and interdependencies. Learning models are necessary to inform effective education practice. In this study, a hypothetical *Learning Domains Wheel* was used to analyze the popular learning domains, including Bloom's [26]. The objective was to categorise outcomes based on a precision framework that classified PIs into specific learning domains and their learning levels. The empirical findings indicated that it was relatively easier to classify specific PIs for realistic outcomes assessment by using Bloom's 3 learning domains [26], compared with other models that categorize learning domains as knowledge, cognitive, psychomotor, interpersonal, IT, numerical, and communication skills [13]. Classification of specific PIs, according to Bloom's domains and learning levels, resulted in the collection of useful outcomes information for aggregation of ABET program level SOs [26], [40]. This was possible since the majority of the PIs could be uniquely mapped to a specific learning level in each of the 3 domains consequently avoiding any overlap and redundancy [26], [40].

2) 'DESIGN DOWN' MAPPING MODEL FROM GOALS TO PERFORMANCE INDICATORS

Spady's "*design down*" [3]–[6] mapping model was used to develop an authentic OBE design flow linking goals, PEOs, SOs, course objectives, COs and PIs [26], [41], [76]. The mapping model defines an outcome-based framework that provides details regarding specificity of technical language and the breadth and depth of coverage for goals, objectives, outcomes, and PIs, in that hierarchical order [26], [41], [76]. The framework enables easy development and assessment of the various components of a typical OBE 'design down' process [3]–[6]. Goals and objectives consist of generic language for broad application that do not contain demonstrable verbs, field or topic-specific nominal content, or performance criteria. SOs and COs comprise operational action verbs, nominal subject content but do not contain performance scales. Performance criteria are applied with the dimension descriptors in rubrics [57]. As per Adelman (2015), language of PIs should be specific to accurately align with course content and student learning activity [20]. The PIs should be assessed in courses from all phases of a curriculum to achieve learning progression for achieving proficiency in engineering skills [20], [23], [26], [41], [52], [56]–[58], [76].

TABLE 2. 3-level skills grouping methodology of Bloom's revised taxonomy.

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

3) BLOOM'S TAXONOMIC MASTERY LEARNING MODEL AND 3-SKILLS GROUPING METHODOLOGY

Prior research has indicated learning models that group Bloom's learning levels in each domain using a classification of teaching and learning strategies [26], [40]. Since, teaching and learning strategies are dynamic and dependent on learners' potential deficiencies, it is more practical from an assessment stand point, to group learning levels based on degrees of complexity. Table 2 shows a new *3-Level Skills Grouping Methodology* proposed by Hussain and Addas (2015) [36] that groups learning activities for each learning domain that are closely associated to a similar degree of complexity of skills. Accurate grouping models enable a holistic and balanced distribution of learning in courses based on a broad but unique categorization of skills. The *3-Level Skills Grouping Methodology* helps implement an *Ideal Learning Distribution* in course delivery for a given program curriculum. As per this model, *Introductory* (100-200), *Reinforced* (300) and *Mastery* (400) levels courses should target holistic learning by assessing elementary, intermediate and advanced level skills in corresponding progressive proportions aligned with their course outcomes and specific PIs. Therefore, 100 and 200 level courses should offer *Introductory* learning with a majority of elementary level skills to cover fundamental engineering knowledge. *Mastery* learning would be achieved in 400 level courses with a higher proportion of advanced level skills in the cognitive, affective and psychomotor learning domains [26], [36], [40], [76].

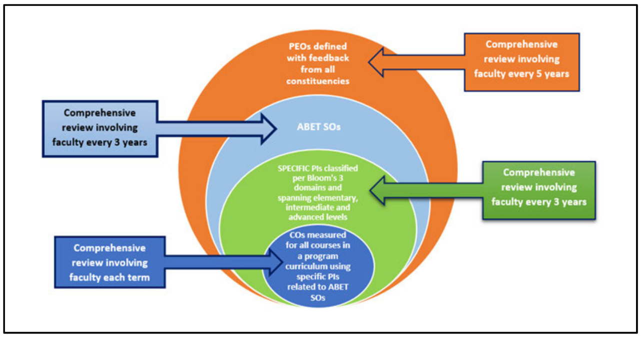


FIGURE 1. Outcomes assessment model implemented by faculty of engineering.

4) ABET ASSESSMENT MODEL

The Faculty of Engineering assessment model shown in Figure 1 was created from authentic OBE frameworks and incorporated regional and ABET accreditation standards and criteria. Notably, all activities in various phases of the quality assurance process involve faculty members who conduct mixed methods reviews of PEOs, SOs, PIs and course work [26], [36], [40], [41], [56], [76]. Specifically, the ABET (2020) self-study criteria: *Student Outcomes* (Criterion 2), *Program Educational Objectives* (Criterion 3) and *Continuous Improvement* (Criterion 4) [11] are incorporated in the assessment model, since they outline the entire assessment structure and provide clear guidelines for program CQI efforts. ABET's *Continuous Improvement* criteria ensure programs make informed quality improvement decisions using SOs assessment data and other stakeholders. Programs employ quantitative and qualitative analyses to evaluate fulfillment of COs, which are assessed using specific PIs, aligned assessments to attain the program SOs [11], [36], [37], [39]–[41], [45], [48], [56], [59].

C. CONCEPTUAL FRAMEWORK – TECHNIQUES, METHODS

1) EMBEDDED ASSESSMENTS METHODOLOGY USING FCAR

Majority of engineering programs pursue a macro level approach when implementing assessment plans for fulfillment of minimal accreditation standards [17]. Generally, programs employ standardized tests for direct assessments that are rescored by independent raters using vague and generic rubrics [65]. Indirect assessments use feedback from focus groups that are identified as course, alumni, and employer surveys [65]. However, these assessment plans do not adequately assess student outcomes aligned to actual course learning activities nor do they provide any formative information for real-time enhancement of any given cohort's learning. According to Cross (2005), if programs adopt comprehensive course assessment plans that can accurately align with and help attain program level SOs, then both qualities teaching as well as accreditation standards can be achieved [64]. These plans can be practically implemented using embedded assessments often called "*classroom-based*" assessments. Instructional materials and routine classwork activity is designed to align with course outcomes and specific PIs. Accurate alignment enables proper use of course embedded assessments to measure attainment of program level SOs by using routine classroom generated artifacts. Therefore, embedded assessments can save programs from significant expenditure of resources otherwise spent in creating additional assessments or in using independent raters for SOs assessment [26], [40], [41], [76].

The EAMU performance vector is the basis of the embedded assessment model in the FCAR [45], [68], [69]. The EAMU performance vector [69], [70] maintains a count of the number of students whose performance for a given outcome was rated with *Excellent* (E), *Adequate* (A), *Minimal* (M), or *Unsatisfactory* (U) levels. Where the EAMU levels are specifically defined by attainment of the following scores: E: scores $>= 90\%$; A: scores $>= 75\%$ and $< 90\%$; M: scores $>= 60\%$ and $< 75\%$; and U: scores $< 60\%$. Instructors report reflections in the FCAR for failing COs, SOs, PIs, and provide student feedback. New actions are generated based on this course reflections. Old action items from previous classes for the same course is ported into the FCAR if it is reoffered. Course delivery in a given term is modified based on recommendations incorporated from the carried over old actions. [45], [68], [69].

2) DESIGN RULES FOR COs AND PIs

A consistent standard for writing outcome statements was developed using: 1) Spady's (1992, 1994 a, b) basic guidelines related to the language of outcomes [4]–[6] 2) Adelman's (2015) construct of outcomes using verbs and nominal subject content [20] and 3) Mager's (1962) work on the hierarchical structure of outcomes [71]. Several essential principles for writing outcome statements were extracted from this standard providing detailed design rules for COs and PIs ensuring tight alignment with actual student learning activity [36], [41], [54], [56], [76]. The key principles are that the outcomes should be specific and measurable consisting of operational action verbs and nominal content. These could be compounded with multiple statements represented by PIs. The design rules for COs and PIs are based on these key principles that enable holistic coverage of course content while maintaining required learning progression of all relevant engineering topics to achieve an ideal learning distribution [36], [41], [54], [56], [76].

3) HYBRID RUBRIC

Jonson and Svingby (2007) reviewed 75 empirical studies on the application and benefits of rubrics [11]. Their finding concluded that analytic rubrics, with topic specific descriptors, exemplars and rater training, offer the most benefits to the practice of teaching and learning. Hussain and Spady (2017) elaborated on a hybrid rubric that was a combination of the holistic and analytic rubric to assess complex learning experiences for developing specific engineering activity that cannot rely on vague and generic performance

SO4: An ability to recognize ethical and professional responsibilities to engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

Health and Safety Constraints

[abet_PI_4_12] Affective: Internalizing values Evaluate the final prototype for (a) implementation of required safety factors in engineering design; (b) health and safety hazards in manufacturing/implementation/operation phases related to resources/ consumables utilization, reuse of byproduct of combustible fuels, carcinogenic materials, noise injury, toxic emissions, biological contagions, ergonomic conditions, seismic conditions, radioactive materials exposures etc.; (c) the maintenance and calibration details and implementations for safe operation of all electrical/ electronic equipment; implement safe supply of electricity ; ensure all electrical/ electronic equipment/components/systems are certified and electrically safe; check life safety implementation while dealing with RF and high voltage equipment; verify equipment handling and safety management instructions for product life time; to conform to the minimum acceptable limits set by the IEEE/national/international codes/standards and regulations

Score	Excellent (90-100%)	Adequate (75-89%)	Minimal (60-75%)	Unsatisfactory (0-60%)
25%	Implement **all** required safety factors in engineering design	Implement **most** required safety factors in engineering design **AND/OR**	Implement **some** required safety factors in engineering design **AND/OR**	**Unable** to implement **some** required safety factors in engineering design **AND/OR**
25%	Provide **all** details of how health and safety hazards were minimized in manufacturing/implementation/operation phases related to resources/ consumables utilization, reuse of byproduct of combustible fuels, carcinogenic materials, noise injury, toxic emissions, biological contagions, ergonomic conditions, seismic conditions, handling RF and high voltage equipment, radioactive materials exposures etc.;	Provide **most** details of how health and safety hazards were minimized in manufacturing/implementation/operation phases related to resources/ consumables utilization, reuse of byproduct of combustible fuels, carcinogenic materials, noise injury, toxic emissions, biological contagions, ergonomic conditions, seismic conditions, radioactive materials exposures etc. **AND/OR**	Provide **some** details of how health and safety hazards were minimized in manufacturing/implementation/operation phases related to resources/ consumables utilization, reuse of byproduct of combustible fuels, carcinogenic materials, noise injury, toxic emissions, biological contagions, ergonomic conditions, seismic conditions, radioactive materials exposures etc. **AND/OR**	Multiple deficiencies to provide **some** details of how health and safety hazards were minimized in manufacturing/implementation/operation phases related to resources/ consumables utilization, reuse of byproduct of combustible fuels, carcinogenic materials, noise injury, toxic emissions, biological contagions, ergonomic conditions, seismic conditions, radioactive materials exposures etc. **AND/OR**
25%	Provide **all** maintenance and calibration details and implementations for safe operation of all engineering equipment;	Provide **most** maintenance and calibration details and implementations for safe operation of all engineering equipment **AND/OR**	Provide **some** maintenance and calibration details and implementations for safe operation of all engineering equipment; **AND/OR**	**Multiple deficiencies** to provide **some** maintenance and calibration details and implementations for safe operation of all engineering equipment; **AND/OR**
25%	Conform to all the minimum acceptable limits set by the IEEE/ national/international codes/standards and regulations	Conform to **most** minimum acceptable limits set by the IEEE/national/international codes/standards and regulations	Conform to **few** minimum acceptable limits set by the IEEE/national/international codes/standards and regulations	**Multiple deficiencies** to conform to **few** minimum acceptable limits set by the IEEE/national/international codes/standards and regulations

FIGURE 2. **A specific PI 4_12 and its hybrid rubric for assessing health and safety factors aligned to abet SO '4'.**

criteria [41]. The dimensions of the hybrid rubric are topic specific using detailed descriptors for the scored EAMU scales providing accurate details or steps of required student performances [41]. The hybrid rubrics address the two main criteria of a qualified assessment: (a) validity: achieve precision and accuracy by tight alignment with outcomes and PIs; and (b) inter/intra-rater reliability: by providing specific details of acceptable student performances [41]. The Hybrid Rubrics provide structured instruction that is aligned to outcomes assessments. Figure 2 shows a hybrid rubric for specific PI_4_12 to evaluate a final engineering prototype for fulfillment of health and safety constraints. The hybrid rubrics aligned to PI_4_12 help assess attainment of ABET SO '4', which targets skills for recognizing ethical and professional responsibilities for specific engineering situations and to make informed judgements about the impact of engineering solutions in global, economic, environmental, and societal contexts.

4) WEIGHTING FACTORS

Moon, 2007 [7] and Liu and Chen, 2012 [69] suggested applying weights when aggregating learning outcomes for varying proficiency. Hussain, Mak and Addas (2016) achieved this at the course level by specifying weights to different assessments according to a combination of their course grading policy and assessment type [26], [40]. The primary rationale given for applying weights to varying types of assessment considers their level of comprehension and holistic coverage. For example, higher weightage is allocated for assessments that measure laboratory or design work especially when they involve learning in all the three domains of Bloom's taxonomy [29], cognitive, psychomotor and affective versus purely theoretical work [52]; or final exams over quizzes since they are relatively more comprehensive, with students' skills reaching a higher level of maturity and proficiency by then [26], [40]. The secondary rationale considers the course grading scale which accounts for a given assessment's percentage contribution of assessments to the final grade [26], [40].

D. PRACTICAL FRAMEWORK – DIGITAL PLATFORM EVALTOOLS ®

Several engineering programs have utilized additional software applications such as True Outcomes® to compensate for comprehensive and accurate outcomes for assessment standards that are not features of Blackboard® [34]. The Faculty of Engineering chose EvalTools® 6 since it is the only current tool employing the embedded assessment model using the FCAR and EAMU performance vector methodology [36], [40], [45], [47], [68]. EvalTools® enables high levels of faculty involvement in CQI processes with full-scale automation achieved by integrating the Administrative Assistant (AAS), Learning Management (LMS), Outcomes Assessment (OAS) and Continuous Improvement Management (CIMS) Systems [36], [40], [45], [47], [68], [76]. The CIMS electronically integrates multiple results of term review outcomes from programs with CQI input from 20 standing administrative committees at the Faculty of Engineering.

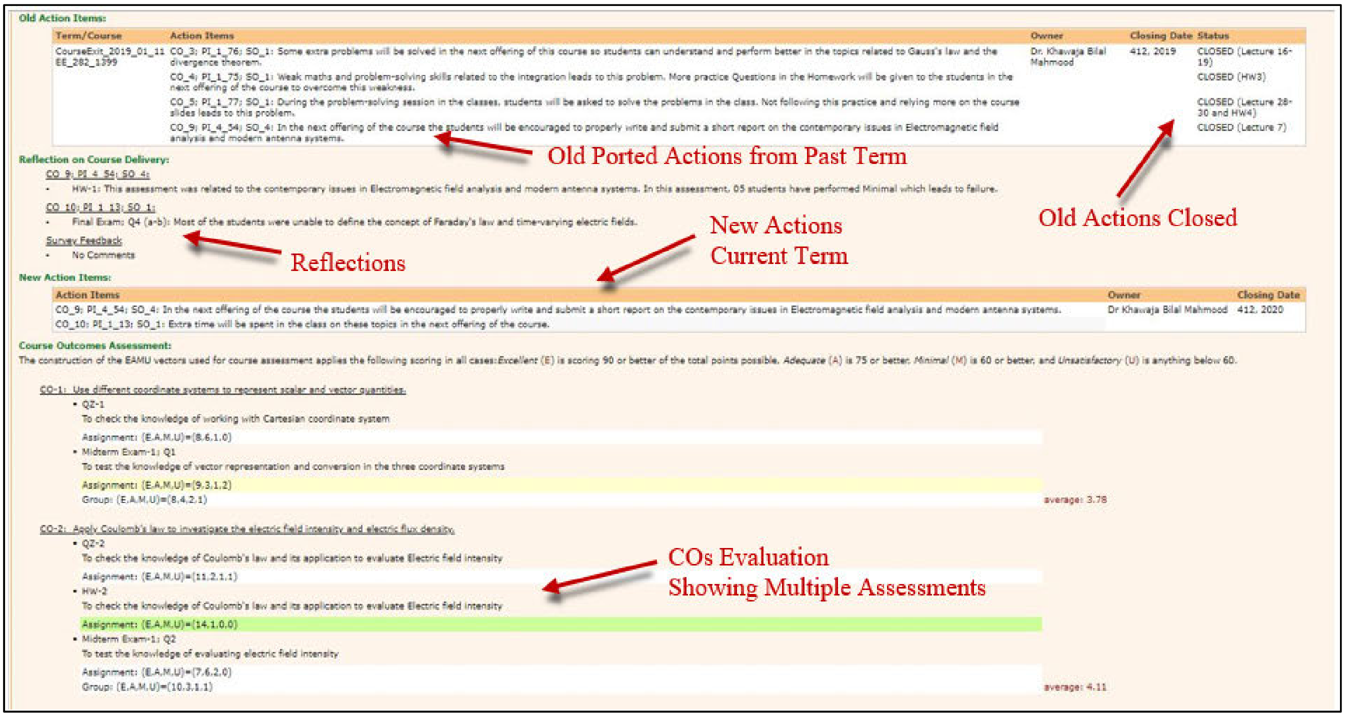


FIGURE 3. FCAR - actions, reflections and COs evaluation.

All corrective actions are generated with electronic ID, time stamp, priority and closure status to enable quality assurance processes. Therefore FCAR saves considerable amounts of precious teaching resources because outcomes assessments are automated and reported [35], [44], [45], [68]. When embedded assessments are aligned with learning outcomes, there is practical efficacy as indicated by Mead and Bennet (2009) [31]. Their findings highlighted the importance of creating specific performance criteria and corresponding rubrics to enable accurate alignment of assessments to actual student learning activities [31]. However, their work mainly concentrated on cognitive skills. Hussain, Mak and Addas proposed an enhanced FCAR + Specific PIs methodology using EvalTools® to implement holistic delivery of engineering curriculum by comprehensively covering all the 3 domains and associated learning levels of Bloom's Taxonomy. Table 3 presents the generic performance criteria for EAMU levels and heuristic rules for PVT applied to cohort or program level evaluations [26], [36], [40], [44], [45], [68], [76]. However, instructors can also opt to apply performance criteria of hybrid rubrics for assessing specific PIs of interest.

As shown in Figure 3, EvalTools® 6 employs a structured format for its FCAR module which consists of course descriptions, survey feedback results, grade distributions, COs evaluations, assignment lists, reflections, old and new action items, and SOs and PIs evaluations [36], [40], [45], [47], [68], [76]. Specifically, COs evaluation employs EAMU weighted averaging across various types of assessments aligned with specific PIs [36], [40], [45], [47], [68]. For example, CO1 is evaluated using assessments QZ1 and MidTerm Exam-I Q1 that measure skills related to their corresponding specific PIs.

TABLE 3. Heuristic rules for performance criteria.

Specification of EAMU performance indicator levels:

Category –Scale%	Description
Excellent (E) (90 – 100)	Apply knowledge with virtually no conceptual or procedural errors
Adequate (A) (75 - 90)	Apply knowledge without significant conceptual errors and only minor procedural errors
Minimal (M) (60 – 75)	Apply knowledge with occasional conceptual errors and only minor procedural errors
Unsatisfactory (U) (0 - 60)	Significant conceptual and/or procedural errors when applying knowledge

Heuristic rules for Performance Vector Tables (PVT):

Category	General Description
Red Flag	Any performance vector with an average below 3.3 and a level of unsatisfactory performance (U) that exceeds 10%
Yellow Flag	Any performance vector with an average below 3.3 or a level of unsatisfactory performance (U) that exceeds 10%, but not both
Green Flag	Any performance vector with an average that is at least greater than 4.6 and no indication of unsatisfactory performance (U)
No Flag	Any performance vector that does not fall into one of the above categories

E. PRACTICAL FRAMEWORK – SUMMARY OF DIGITAL TECHNOLOGY AND ASSESSMENT METHODOLOGY

The Faculty of Engineering studied several manual and automated CQI systems for developing an authentic outcome-based IQMS that offers efficient functionality and seamless implementation to achieve desired quality improvement and not just minimal accreditation standards. [21], [22], [24], [30], [31], [34], [35], [37], [38], [42]–[44], [46], [68]. Sixteen essential elements were identified by the Faculty to attain cutting edge assessment methodology. This uses state-of-the-art digital technology for achieving a high level of automation and realistic CQI for engineering education [26], [40], [72], [76]:

1. OBE assessment model.
2. ABET, EAC outcomes assessment model employing PEOs, 11/7 ABET EAC SOs and PIs to measure COs.
3. Measurement of outcomes information in all course levels of a program curriculum: introductory, reinforced and mastery.
4. The FCAR utilizing the EAMU performance vector methodology.
5. Well-defined performance criteria for course and program levels.
6. A digital database of specific PIs and their hybrid rubrics classified as per Bloom's revised 3 domains of learning and their associated levels (according to the *3-Level Skills Grouping Methodology*).
7. Unique Assessment mapping to one specific PI.
8. Scientific Constructive Alignment for designing assessments to obtain realistic outcomes data representing information for one specific PI per assessment.
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 type of assessments, PIs and course levels.
11. Program as well as student performance evaluations considering their respective measured ABET SOs and associated PIs as a relevant indicator scheme.
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.
13. A student academic advising module based on measured learning 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.
15. Electronic integration of 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.

V. SOs AND PIS EVALUATIONS

The program term review evaluation process involves three distinct phases: *SOs, PIs* and *Learning Domains Evaluations* [26], [40], [56], [76]. The program term reviews determine SOs and PIs failures, course actions and whenever necessary report on program level improvement actions and their associated corrective actions. The term summary report consists of composite histogram plots showing SOs and PIs evaluation results, detailed information on contributing courses, and EAMU PVT values for all assessed PIs [26], [40], [56], [76]. The Final SO values for a given term are computed by applying a High Frequency Weighting Factor Scheme (HFWFS) to aggregate PIs results obtained by accessing student performances at the course level [26], [40], [41], [56], [76]. The HFWFS based PIs aggregation gives higher priority to advanced skill levels and mastery level courses. Figure 4 shows a sample EE program, term 391 (Fall, 2018), PIs evaluation for the revised ABET SO_5 related to team work skills. Failing PIs are easily identified and examined based on color coded results that correspond with the performance criteria listed in Table 3.

EvalTools® term summary reports consist of the following evaluation reports [40], [56], [76]:

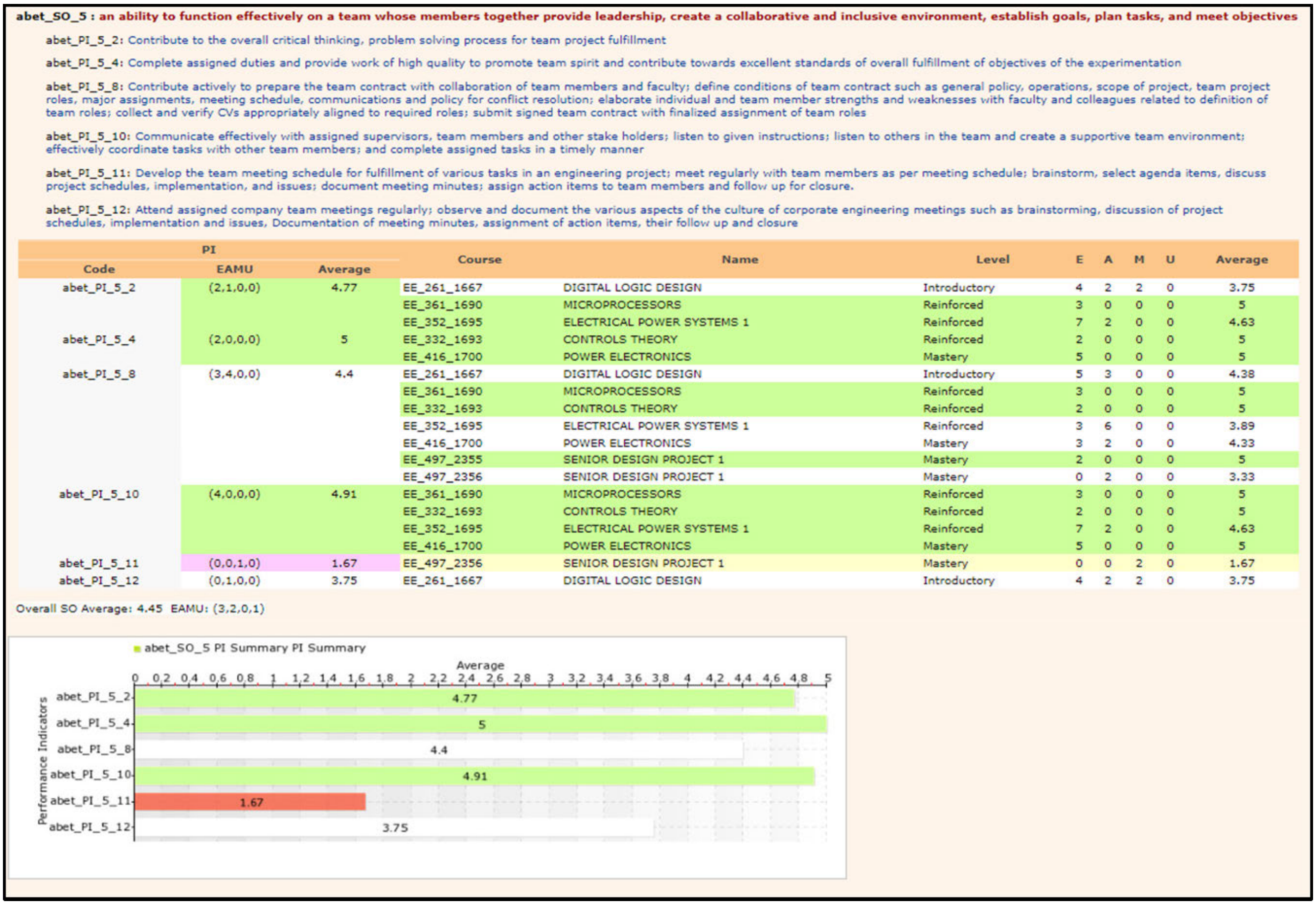
a) SO executive summary
b) Detailed SO/PI executive summary
c) SO/PI Performance Vector Table PVT summary and
d) Course reflections/action items

A. DIRECT ASSESSMENT OF SOS – A SAMPLE FROM A SINGLE TERM 382 ANALYSIS

In this section, we present the results of direct assessments for a single term as a sample. The section below presents a program evaluation conducted in term 382 (Spring 2018) and refers to outcomes assessment evaluations for ABET SOs (a-k). Table 4 shows a summary of EE program committee decisions *Exceeding, Meeting* or *Below Expectations* (*EE, ME or BE*) for an overall review of ABET SOs (a-k) score results in a program term review term 382 (Spring 2018). Figure 5 shows a composite plot for ABET SOs (a-k) obtained from an EE program term review term 382. The Red, Yellow, Green and White flags have already been explained in Table 3 listing performance criteria.

VI. PDCA QUALITY CYCLE Q5: SOS MULTI-TERM REVIEW RESULTS

The IQMS implemented at the Faculty of Engineering incorporates six Plan, Do, Check, ACT (PDCA) Quality Cycles Q_1 to Q_6. The six quality cycles ensure course and program level teaching, learning, assessment, evaluation, feedback and CQI processes adhere to specified quality and accreditation standards [56], [76]. As shown in Figure 6, the PDCA quality cycle Q_5 involves program level SO reviews over multiple terms and conducted by faculty every three years [55], [56], [76]. A comprehensive multi-term impact evaluation uses regression analyses for at least six terms of program level quantitative SOs data followed with



abet_SO_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

abet_PI_5_2: Contribute to the overall critical thinking, problem solving process for team project fulfillment

abet_PI_5_4: Complete assigned duties and provide work of high quality to promote team spirit and contribute towards excellent standards of overall fulfillment of objectives of the experimentation

abet_PI_5_8: Contribute actively to prepare the team contract with collaboration of team members and faculty; define conditions of team contract such as general policy, operations, scope of project, team project roles, major assignments, meeting schedule, communications and policy for conflict resolution; elaborate individual and team member strengths and weaknesses with faculty and colleagues related to definition of team roles; collect and verify CVs appropriately aligned to required roles; submit signed team contract with finalized assignment of team roles

abet_PI_5_10: Communicate effectively with assigned supervisors, team members and other stake holders; listen to given instructions; listen to others in the team and create a supportive team environment; effectively coordinate tasks with other team members; and complete assigned tasks in a timely manner

abet_PI_5_11: Develop the team meeting schedule for fulfillment of various tasks in an engineering project; meet regularly with team members as per meeting schedule; brainstorm, select agenda items, discuss project schedules, implementation, and issues; document meeting minutes; assign action items to team members and follow up for closure.

abet_PI_5_12: Attend assigned company team meetings regularly; observe and document the various aspects of the culture of corporate engineering meetings such as brainstorming, discussion of project schedules, implementation and issues, Documentation of meeting minutes, assignment of action items, their follow up and closure

PI			Course	Name	Level	E	A	M	U	Average
Code	EAMU	Average								
abet_PI_5_2	(2,1,0,0)	4.77	EE_261_1667	DIGITAL LOGIC DESIGN	Introductory	4	2	2	0	3.75
			EE_361_1690	MICROPROCESSORS	Reinforced	3	0	0	0	5
			EE_352_1695	ELECTRICAL POWER SYSTEMS 1	Reinforced	7	2	0	0	4.63
abet_PI_5_4	(2,0,0,0)	5	EE_332_1693	CONTROLS THEORY	Reinforced	2	0	0	0	5
			EE_416_1700	POWER ELECTRONICS	Mastery	5	0	0	0	5
abet_PI_5_8	(3,4,0,0)	4.4	EE_261_1667	DIGITAL LOGIC DESIGN	Introductory	5	3	0	0	4.38
			EE_361_1690	MICROPROCESSORS	Reinforced	3	0	0	0	5
			EE_332_1693	CONTROLS THEORY	Reinforced	2	0	0	0	5
			EE_352_1695	ELECTRICAL POWER SYSTEMS 1	Reinforced	3	6	0	0	3.89
			EE_416_1700	POWER ELECTRONICS	Mastery	3	2	0	0	4.33
			EE_497_2355	SENIOR DESIGN PROJECT 1	Mastery	2	0	0	0	5
			EE_497_2356	SENIOR DESIGN PROJECT 1	Mastery	0	2	0	0	3.33
abet_PI_5_10	(4,0,0,0)	4.91	EE_361_1690	MICROPROCESSORS	Reinforced	3	0	0	0	5
			EE_332_1693	CONTROLS THEORY	Reinforced	2	0	0	0	5
			EE_352_1695	ELECTRICAL POWER SYSTEMS 1	Reinforced	7	2	0	0	4.63
			EE_416_1700	POWER ELECTRONICS	Mastery	5	0	0	0	5
abet_PI_5_11	(0,0,1,0)	1.67	EE_497_2356	SENIOR DESIGN PROJECT 1	Mastery	0	0	2	0	1.67
abet_PI_5_12	(0,1,0,0)	3.75	EE_261_1667	DIGITAL LOGIC DESIGN	Introductory	4	2	2	0	3.75

Overall SO Average: 4.45 EAMU: (3,2,0,1)

FIGURE 4. ABET SOs (1-7) evaluation module for term 391 (fall 2018) showing PIs assessed for abet revised SO 5 (teamwork skills).

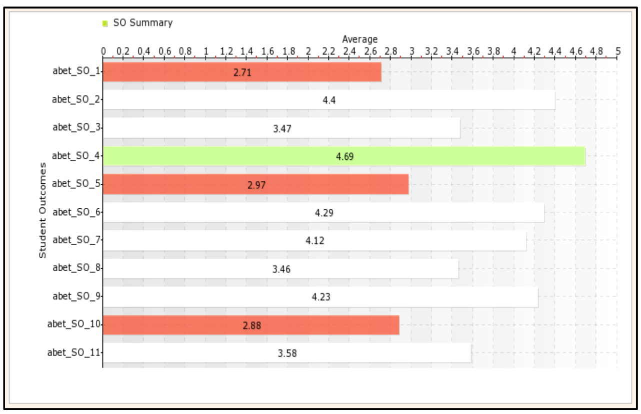


FIGURE 5. ABET SOs (a-k) composite plot EE program term review term 382 (spring 2018).

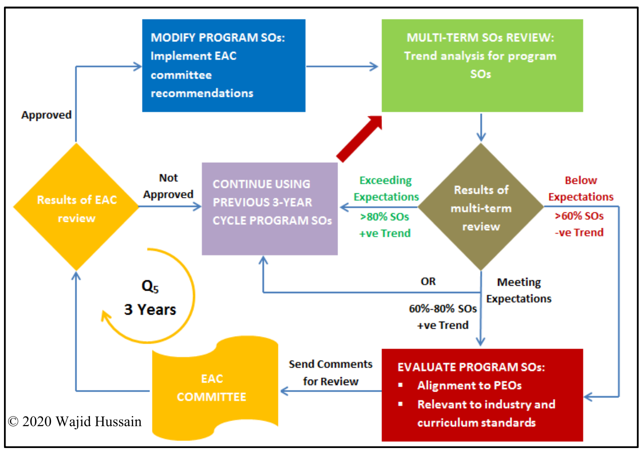


FIGURE 6. PDCA quality cycle Q5: SOs multi-term review process flow.

application of precision rubrics to estimate the improvement in overall SOs trend performance [55], [56], [76].

As per the process flow indicated in Figure 6, based on the quantitative results of the multi-term SOs trend analyses, the program reviews would result in either of the three decisions: a) *Exceeding Expectations*, if more than 80% of the total number of SOs exhibit a positive trend b) *Meeting Expectations*, if 60% to 80% of the total number of program SOs display an improving trend and c) *Below Expectations*, when more than 60% of the total number of program SOs exhibit a negative trend in overall performance. A *Below Expectations* decision mandates an examination of language, content and

TABLE 4. Executive summary report for term 382 (spring 2018).

SO	Student Outcomes	Avg.	Result
1	an ability to apply knowledge of mathematics, science, and engineering	2.71	BE
2	an ability to design and conduct experiments, as well as to analyze and interpret data	4.40	ME
3	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	3.47	ME
4	an ability to function on multidisciplinary teams	4.69	ME
5	an ability to identify, formulate, and solve engineering problems	2.97	BE
6	an understanding of professional and ethical responsibility	4.29	ME
7	an ability to communicate effectively	4.12	ME
8	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	3.46	ME
9	a recognition of the need for, and an ability to engage in life-long learning	4.23	ME
10	a knowledge of contemporary issues	2.88	BE
11	an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	3.58	ME

scope of the failing SOs besides any other corrective actions. A detailed multi-term SOs impact evaluation report including recommendations for improvement and any modifications to SOs is sent to the *External Advisory Committee* (EAC) for review and approval.

For gaining a better understanding of the impact evaluation process, the following sections provide detailed information regarding various SOs, PIs evaluation reports and rubrics that form the basis for program committees' review discussion and decision process:

1. *Multi-term Executive Summary Report - SOs Attainment* results for multi-year [2014-18] ABET SOs (a-k) data.
2. *Multi-term Executive Summary Report —— PIs Evaluation.*
3. *Multi-term Executive Summary Report —— SOs Trend Plots.*
4. Rubrics establishing performance criteria for SOs trend analyses.
5. ME program sample showing trend analysis using regression methods for SO 'a' (SO_1), "*an ability to apply knowledge of mathematics, science, and engineering*".
6. *Multi-term Executive Summary Report —— Program Committee Review* of trend analysis for ME SO 'a' (SO_1).
7. Impact evaluation for the EE, ME and CE programs based on summary of results of trend analyses for ABET SOs (a-k).

A. MULTI-TERM EXECUTIVE SUMMARY REPORT – SOs ATTAINMENT ABET SOs (a-k) FALL 2014 – SPRING 2018 (TERMS 382, 381, 372, 371, 362, 361, 352 AND 351)

In this section, we present summarized data for the attainment of SOs and also samples of EE, ME and CE program level multi-term ABET SOs (a-k) executive summary reports. A summary of 8 terms of ABET SOs (a-k) and CQI data from term 351 (Fall 2014) up to term 382 (Spring 2018) is presented in this section. The multi-term detailed executive summary report presented does not include any data related to the revised ABET SOs (1-7) since the ABET EAC Commission approved changes to the 2019-20 accreditation cycle for implementation in mid-2018. As per the Q_5 PDCA Quality Cycle's assessment plan, the multi-term SOs evaluation is conducted every three years necessitating collection of at least 6 terms of outcomes and CQI data related to revised ABET SOs (1-7). Therefore, a detailed multi-term review related to the revised ABET SOs (1-7) will be conducted in Spring 2022. Tables 5, 6 and 7 below show a summary of EE, ME and CE program committee decisions *Exceeding, Meeting* or *Below Expectations* for overall review of ABET SOs (a-k) score results spanning 8 terms from term 351 (Fall 2014) up to term 382 (Spring 2018). The Red, Yellow, Green and White flags and criteria for *Exceeding, Meeting* and *Below Expectations* (*EE, ME, BE*) have already been explained in Table 3

B. ME PROGRAM SAMPLE - MULTI-TERM EXECUTIVE SUMMARY REPORT PIs EVALUATION FOR ABET SOs (a-k)

Since the multi-term executive summary reports are detailed and lengthy, running into tens of pages for each program, we present a small portion of the ME program's multi-term report as a sample in Table 8 for just SO 'g' (SO_7) on "*an ability to communicate effectively*". The executive summary report shows a list of PIs, courses assessed, terms covered followed by summarized notes and actions by attending program faculty members for deficiencies reviewed during program term reviews spanning Fall 2014 to Spring 2018 time period. The overall summary includes a program level decision of whether the ABET SO is *Exceeding, Meeting* or *Below Expectations*. The actions of the multi-term SOs executive summary report mainly involve either review and approval of faculty actions in the FCAR or their elevation to the program level for assignment to administrative committees for closure.

TABLE 5. EE program multi-term executive summary report fall 2014 to spring 2018 (terms 382, 381, 372, 371, 362, 361, 352 and 351).

SO	382 2018		381 2017		372 2017		371 2016		362 2016		361 2015		352 2015		351 2014	
	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result
SO_1	2.71	BE	2.80	BE	2.81	BE	2.35	BE	1.98	BE	2.50	BE	1.80	BE	2.69	BE
SO_2	4.40	ME	4.10	ME	3.83	ME	3.47	ME	3.42	ME	2.97	BE	3.67	ME	4.32	ME
SO_3	3.47	ME	3.78	ME	4.04	ME	3.33	ME	2.64	BE	1.67	BE	2.96	ME	1.76	BE
SO_4	4.69	ME	4.59	ME	4.40	ME	4.35	ME	2.43	BE	0.00	BE		N/A	4.49	ME
SO_5	2.97	BE	2.89	BE	2.96	BE	2.08	BE	2.05	BE	2.48	BE	2.61	BE	3.14	BE
SO_6	4.29	ME	3.16	BE	3.66	ME	2.98	BE	2.88	BE	1.96	BE		N/A		N/A
SO_7	4.12	ME	3.56	ME	3.94	ME	4.32	ME	3.52	ME	3.06	BE		N/A	0.49	BE
SO_8	3.46	ME	3.73	ME	4.02	ME	4.43	ME	2.76	BE	0.71	BE		N/A		N/A
SO_9	4.23	ME	3.85	ME	3.64	ME	4.27	ME	4.58	ME		N/A		N/A		N/A
SO_10	2.88	BE	3.39	ME	1.43	BE	2.54	BE	4.72	ME	2.14	BE		N/A		N/A
SO_11	3.58	ME	3.22	BE	3.27	BE	2.61	BE	2.13	BE	1.81	BE	1.63	BE	2.82	BE

C. ME SAMPLE MULTI-TERM EXECUTIVE SUMMARY REPORT - SOs TREND PLOTS

Multi-term Trend plots for ME program sample for ABET SOs (a-k) terms 351 to 382 (Fall 2014 to Spring 2018) are shown in Figure 7. Most of the ABET SOs (a-k) display a stable average with variance under 30% and notable improvement in performance with an increasing trend in average values reported in ME program term reviews data for the Fall 2014 to Spring 2018 time period.

D. RUBRICS ESTABLISHING PERFORMANCE CRITERIA FOR MULTI-TERM SOs TREND ANALYSES

Table 9 shows rubrics the Faculty of Engineering EE, ME and CE programs employ to establish performance criteria for multi-term SOs trend analyses. The non-experimental impact evaluation approach applied in this study involves regression methods and rubrics instead of an explicit comparison group. A linear regression based trend analysis is employed to evaluate the multi-term trend performance of SOs (a-k). The next year's forecast for the SO performance is extrapolated from the linear trend. This forecast is then compared with the average of SO values collected from the 351-382 terms to obtain the percentage increase. The SO's next year forecast value and percentage increase are compared to ranges as described in Table 9 to define seven case types and obtain the *Below, Meeting* and *Exceeding Expectations* review decisions for each SO.

E. OVERALL AVERAGE AND NEXT YEAR'S FORECAST FOR MULTI-TERM SOs TREND ANALYSES

As shown in Table 10, SO 'a' (SO_1) average values obtained for ME program terms 351-382 are input as excel data and averaged to obtain the *Overall Average*. A linear regression trend curve is then used to estimate the following year's forecasted SO 'a' (SO_1) value. Figure 8 shows the linear regression based trend curve obtained using excel for multi-term SO 'a' values. The percentage increase '% INCREASE' is computed by dividing the multi-term overall SO 'a' average value with the next year's forecasted SO 'a' value.

F. MULTI-TERM EXECUTIVE SUMMARY REPORT – PROGRAM COMMITTEE REVIEW SOs (a-k) TREND ANALYSES

For brevity, a portion of the ME program's multi-term SOs (a-k) Trend Analysis Executive Summary Report for SO 'a' (SO_1) is shown in Table 11. The report indicates multi-term (351-382) SO 'a' (SO_1) data, trend curve, list of ME program reviewers, comments, corrective action, date of review

TABLE 6. ME program multi-term executive summary report fall 2014 to spring 2018 (terms 382, 381, 372, 371, 362, 361, 352 and 351).

SO	382 2018		381 2017		372 2017		371 2016		362 2016		361 2015		352 2015		351 2014	
	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result
SO_1	3.35	ME	3.28	BE	3.41	ME	3.71	ME	2.60	BE	2.63	BE	1.79	BE	3.53	ME
SO_2	4.49	ME	3.65	ME	3.62	ME	3.57	ME	3.97	ME	3.56	ME	3.78	ME	4.52	ME
SO_3	4.06	ME	3.86	ME	4.24	ME	3.08	BE	3.34	ME		N/A		N/A		N/A
SO_4	4.61	ME	4.11	ME	4.93	ME	4.15	ME		N/A		N/A		N/A		N/A
SO_5	3.58	ME	3.30	ME	3.13	BE	3.21	BE	3.17	BE	2.22	BE	2.29	BE	2.89	BE
SO_6	3.53	ME	3.41	ME	4.40	ME	2.88	ME		N/A	3.33	ME		N/A		N/A
SO_7	4.42	ME	3.81	ME	4.67	ME	3.60	ME	3.88	ME		N/A	2.25	BE	3.41	BE
SO_8	3.79	ME	3.36	ME	4.02	ME	3.66	ME		N/A		N/A		N/A		N/A
SO_9	4.17	ME	3.33	ME	4.51	ME	3.87	ME		N/A		N/A		N/A		N/A
SO_10	3.60	ME	1.68	BE		N/A		N/A		N/A		N/A		N/A		N/A
SO_11	3.14	BE	3.18	BE	3.14	BE	3.52	ME	3.13	BE	3.59	ME	2.81	BE	3.08	BE

and review decision of Exceeding Expectations for SO 'a' multi-term trend analysis.

abet_SO_1: an ability to apply knowledge of mathematics, science, and engineering

Classification: **Exceeding Expectations**
Discussion:

AVERAGE = 3.0375;

FORECAST = 3.668690476;

% INCREASE = 20.7799334;

STANDARD DEVIATION = 0.68;

STANDARD ERROR = 0.24;

According to multi-term SOs trend analysis performance criteria this is ***Case 3***: Forecast after 1 year ≥ 3.0 AND < 4.0 with ≥ 10% increase compared to AVERAGE

The Review Decision for this SO is ***EXCEEDING EXPECTATIONS***

Action: No action

Reviewers:

Dr. KHT, Dr. MO, Dr. MA, Dr. AS, Dr. SZ, Dr. ERIM, Dr. MB, Mr. MF, Mr. YA, Mr. ANS, Mr. WH

Review Date:2018-09-03

G. IMPACT EVALUATIONS ME, CE AND EE PROGRAMS BASED ON SUMMARY OF RESULTS OF TREND ANALYSES FOR ABET SOs (a-k)

Impact evaluations of the ME, CE and EE programs involve a mixed methods review of the multi-term executive summary and trend analyses reports by the Program and External Advisory Committees (EAC) every 3-5 years to establish final review decisions and initiate any necessary corrective actions to:

1. Benchmark and adjust the existing performance criteria
2. Review coverage of SOs data coupled with faculty feedback of the validity/reliability of current assessment and evaluation data/process of individual SOs
3. Abrogate, modify or delete any SOs (refer to recommended actions for cases 4,6 and 7 mentioned in Table 9).

Based on the rubrics establishing the performance criteria shown in Table 9 and the PDCA Quality Cycle Q5: *SOs Multi-Term Review Process Flow* shown in Figure 6 the ME, CE and EE program committees arrived at the following final review decisions for the impact evaluations of ABET SOs (a-k) 5-year [2014-18] trend analyses:

1) ME PROGRAM FINAL REVIEW DECISION

Table 12 summarizes the ABET SOs (a-k) overall average, % increase, next year forecast, case type, review date and review decision data for the ME program.

Since 8 out of 11 SOs, 60-80% of SOs results were either *Exceeding* or *Meeting Expectations*, an overall review

TABLE 7. CE program multi-term executive summary report fall 2014 to spring 2018 (terms 382, 381, 372, 371, 362, 361, 352 and 351).

SO	382 2018		381 2017		372 2017		371 2016		362 2016		361 2015		352 2015		351 2014	
	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result
SO_1	3.89	ME	3.82	ME	3.67	ME	3.95	ME	2.57	BE	3.49	ME	2.23	BE	3.10	BE
SO_2	4.73	ME	4.32	ME	4.28	ME	3.80	ME	3.15	BE	3.12	BE	3.64	ME	3.14	BE
SO_3	3.08	BE	3.99	ME	3.66	ME	3.62	ME	2.41	BE	3.68	ME		N/A		N/A
SO_4	4.47	ME	4.50	ME	4.74	ME	4.76	ME		N/A		N/A		N/A		N/A
SO_5	3.34	ME	3.05	BE	3.26	BE	2.80	BE	3.20	BE	2.90	BE	2.35	BE	3.35	ME
SO_6	3.42	ME	2.92	BE	3.50	ME	3.89	ME		N/A		N/A		N/A		N/A
SO_7	4.34	ME	3.49	ME	3.39	ME	3.99	ME	2.64	BE	3.66	ME		N/A		N/A
SO_8	4.22	ME	3.76	ME	4.00	ME	2.14	BE	2.41	BE	1.25	BE		N/A		N/A
SO_9	4.30	ME	4.63	ME	3.13	ME	4.49	ME		N/A		N/A		N/A		N/A
SO_10	3.47	ME	2.82	BE	4.07	ME	3.33	ME		N/A		N/A		N/A		N/A
SO_11	3.64	ME	3.43	ME	3.45	ME	3.58	ME	3.31	BE	3.20	BE	2.13	BE	3.09	BE

decision of *Meeting Expectations* was obtained for the ME program. Figure 9 shows the meeting minutes for *Meeting ID ME:MTG:2018-09-03:V57* which indicate the ME program's overall review decision for 11 SOs (a-k) multi-term (351-382) trend analysis as *Meeting Expectations*.

2) CE PROGRAM FINAL REVIEW DECISION

Table 13 summarizes the ABET SOs (a-k) overall average, % increase, next year forecast, case type, review date and review decision data for the CE program. Since 10 out of 11 SOs, >80% of SOs results were either *Exceeding* or *Meeting Expectations*, an overall review decision of *Exceeding Expectations* was obtained for the CE program.

3) EE PROGRAM FINAL REVIEW DECISION:

Table 14 summarizes the ABET SOs (a-k) overall average, % increase, next year forecast, case type, review date and review decision data for the EE program. Since 8 out of 11 SOs, 60-80% of SOs results were either *Exceeding* or *Meeting Expectations*, an overall review decision of *Meeting Expectations* was obtained for the EE program.

Table 15 summarizes results of all the three engineering programs by showing overall comments and actions for SOs aggregated values and trend analyses results. As mentioned in Table 9, based on trend forecast, achieved % increase, coverage of SOs data in several terms, and faculty feedback, the following general observations were recorded and corresponding actions taken:

1. The majority of SOs (a-k) performances just stabilized to aggregate SOs values with a *Meeting Expectations* result in the last few terms towards 382 and therefore did not require any modifications to performance criteria. If *Meeting* or *Exceeding Expectations* results were observed in multiple terms for any of the SOs, then the minimum performance criteria would have been raised to increase the performance standards.
2. The majority of SOs trends were positive with reasonable multi-term coverage and faculty feedback also indicated acceptable assessment and evaluation data/processes and did not necessitate any modifications to the 11 SOs.

The impact evaluation based on the overall multi-term ABET SOs (a-k) results were therefore acceptable and the CE, ME and EE programs' position to transition to revised 7 ABET SOs was reinforced in the summer of 2018.

VII. DISCUSSION

The driving force behind this research was to examine the benefits and limitations of applying an authentic OBE model to engineering programs to evaluate a holistic and comprehensive educational process that maximizes opportunities for the attainment of successful student learning. The objective was to conduct impact evaluations of the Faculty of Engineering's EE, CE and ME programs by employing a non-experimental approach using regression methods for

TABLE 8. ME program multi-term executive summary report for abet SOs (a-k).

abet_SO_7 : an ability to communicate effectively

abet_PI_7_2: Present technical information with proper Format and Organization

abet_PI_7_3: Communicate Graphical Information

abet_PI_7_4: Write complete technical reports with title, front matter, list of tables and contents, details of overall organization of the report, English(grammar/spelling/sentence structure), abstract/introduction, description of training program, case studies/measurements/supervision and design, theory and field applications, research activities, conclusions & recommendations etc. with proper formatting and style

abet_PI_7_5: Make effective oral presentations in a given time frame to defend course projects with required professionalism, style, slide quality, delivery, response to questions and adequate technical content of problem definition, literature review, design specifications, design estimation and target determination, deliverables, methodology, design decision identification, design concepts, concepts evaluation, concepts selection, detailed design presentation, necessary planning, budget, conclusion, references, appendices etc.

abet_PI_7_12: Communicate on time and effectively with the concerned stake holders using oral and written means in the form of presentations, technical reports, diagrammatic representations using electronic or other media

abet_PI_7_13: Write complete technical reports with title, front matter, list of tables and contents, details of problem definition, literature review, design specifications, design estimation and target determination, deliverables, methodology, design decision identification, design concepts, concepts evaluation, concepts selection, detailed design presentation, necessary planning, budget, conclusion, references, appendices etc. with proper formatting and style.

abet_PI_7_14: Make effective clear oral presentations in given time frame providing details of title, front matter, list of tables and contents, details of overall organization of the report, English(grammar/spelling/sentence structure), abstract/introduction, description of training program, case studies/measurments/supervision and design, theory and field applications, research activities, conclusions & recommendations etc. with proper formatting and style

abet_PI_7_15: Develop an elaborate project proposal for the design of a mechanism related to theory of machines such as gears, cams etc.: provide a summarized project abstract; reference literature survey detailing the construction (components, dimensions), manufacturability (material, facility, costs) and operation (schematic and text detailing inter-related motions) of the mechanism; provide design specifications (customer requirements and constraints); discuss manufacturability of the design (facilities, materials required and costs); provide a detailed project implementation schedule in the form of a Gantt chart.

abet_PI_7_16: Prepare interim Senior Design Report incorporating modifications in literature review, any other suggestion for improvements based on advisor feedback; Write a detail technical report following a specific/standard format to present: Abstract; Problem Definition; Problem Statement; Problem Formulation (Goals of Project, Scope of Project); Literature Review; Design Concepts Development (List all existing design methods, Propose new design methods); Design Evaluation & Selection (Concept Evaluation & Selection, Design Specifications, Constraints, Customer requirements (modifiable with customer agreement)

abet_PI_7_17: Make a professional poster presentation of Capstone design Project; display Abstract, Methodology, Summarized simulation/mathematical Results, conclusions, references; Provide necessary technical diagrams

abet_PI_7_18: Make a professional poster presentation of Capstone design Project; interact with audience, visitors, reviewers; respond/answer questions proactively in an appropriate technical and professional manner.

Student Outcomes	382 2018		381 2017		372 2017		371 2016		362 2016		361 2015		352 2015		351 2014	
	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result	Avg	Result
abet_SO_7	4.42	Meeting Expectations	3.81	Meeting Expectations	4.67	Meeting Expectations	3.60	Meeting Expectations	3.88	Meeting Expectations		N/A	2.25	Below Expectations	3.41	Below Expectations

PI	Assessment Resources	Evaluation							
		382 2018	381 2017	372 2017	371 2016	362 2016	361 2015	352 2015	351 2014
abet_PI_7_2	ME_317_1531 ME_312_1536					EAMU: (0,2,0,0) Avg:3.64			
abet_PI_7_3	ME_262_962 ME_211_1593							EAMU: (0,0,0,1) Avg:2.25 Below Expectations	EAMU: (0,0,1,0) Avg:3.41 Below Expectations
abet_PI_7_4	ME_498_928			EAMU: (1,0,0,0) Avg:4.91					

TABLE 8. ***(Continued.)*** **ME program multi-term executive summary report for abet SOs (a-k).**

abet_PI_7_5	ME_323_2181 ME_413_2200 ME_323_1091 ME_497_1104 ME_323_791 ME_498_928 ME_497_3008	EAMU: (2,0,0,0) Avg:5	EAMU: (1,0,1,0) Avg:3.36	EAMU: (0,2,0,0) Avg:4.09	EAMU: (0,1,0,0) Avg:4.26				
abet_PI_7_12	ME_431_3022				EAMU: (0,1,0,0) Avg:3.61				
abet_PI_7_13	ME_323_2181 ME_413_2200 ME_498_2461 ME_323_1091 ME_497_1104 ME_323_791 ME_498_928 ME_323_2994 ME_497_3008	EAMU: (1,2,0,0) Avg:4.71	EAMU: (0,2,0,0) Avg:4.17	EAMU: (0,1,1,0) Avg:4.25	EAMU: (0,1,1,0) Avg:2.92 Below Expectations	EAMU: (1,2,0,0) Avg:4.05			
	ME_317_1531 ME_334_1532 ME_312_1536								
abet_PI_7_14	ME_498_2461 ME_323_2994	EAMU: (0,1,0,0) Avg:4.5			EAMU: (1,0,0,0) Avg:5				
abet_PI_7_15	ME_323_2181 ME_323_1091 ME_323_791	EAMU: (1,0,0,0) Avg:5	EAMU: (0,1,0,0) Avg:4.17	EAMU: (0,1,0,0) Avg:3.79					
abet_PI_7_16	ME_497_2460 ME_498_2461 ME_498_928	EAMU: (0,2,0,0) Avg:3.75		EAMU: (1,0,0,0) Avg:5					
abet_PI_7_17	ME_498_2461 ME_498_928	EAMU: (0,1,0,0) Avg:4.33		EAMU: (1,0,0,0) Avg:5					
abet_PI_7_18	ME_498_2461 ME_498_928	EAMU: (0,1,0,0) Avg:4.5		EAMU: (1,0,0,0) Avg:5					

trend analyses of ABET SOs (a-k). The Faculty of Engineering programs' multi-term outcomes data was aggregated across thousands of assessment data points collected over 5 years. The data comprise reflections, actions, discussions, decisions based on a detailed review of information from FCARs, COs, PIs, SOs program evaluations. The comprehensive outcomes data, meta-analyses reports and subsequent CQI efforts had a multi-dimensional impact on the opinions of all the constituencies of the engineering programs. Relevant details of CQI results motivated students, alumni and employers to provide valuable feedback, participate in the EAC meetings, surveys or discussions and eventually contribute to several types of program level improvement actions [56], [76]. These actions impacted multiple aspects of the Faculty's quality assurance process resulting in improvements to teaching/learning strategies, direct/indirect assessments, advising, curriculum development, facilities, CQI processes, and an approach for drawing institutional support. The SOs (a-k) multi-term data published in this study is not outdated despite ABET's revised SOs (1-7), since the SOs (a-k) align with the revised ABET SOs [11] and the IEA's Washington Accord 12 current *Graduate Attributes* [16] thereby providing the latest skills-based impact evaluation information to thousands of engineering programs worldwide.

For impact evaluations, we applied the main aspects mentioned by Onwuegbuzie and Hitchcock (2017) to examine the validity and credibility of qualitative and quantitative statistical data as well as type and level of generalizability and transferability [49]. To better understand the statistical power of quantitative data used in the study, we explained how the sampling methodology and accuracy of outcomes evaluation was employed for the Faculty of Engineering programs. Firstly, quantitative outcomes data was collected from direct assessments, following a rigorous quality assurance procedure at both the course and program level. Importantly, embedded assesments using FCAR and PVT technology helped to fulfill OBE's "all students can succeed" paradigm by enabling the collection of specific outcomes data for all enrolled students. Secondly, two types of sampling methods were applied to aggregate course level assessment data. In the first type, any aspect of a given CO was measured using specific PIs and their tightly aligned assessments with higher course grade contributions [36]. The other sampling method involved collecting data from a cohort of students for specific PIs and corresponding COs. In contrast, manual CQI systems

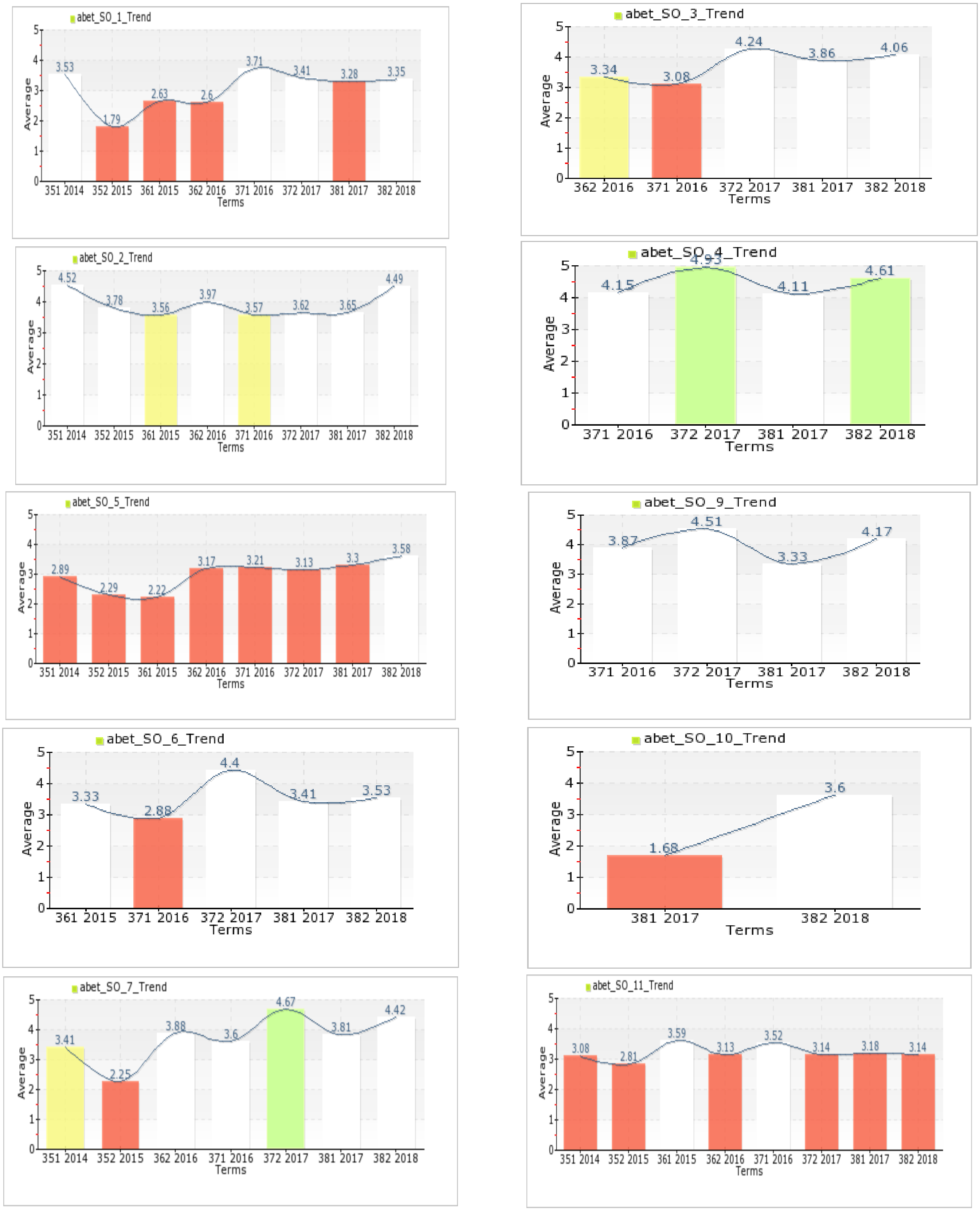


FIGURE 7. Consolidated Plot for ME program abet SOs (a-k) multi-term trend analysis.

TABLE 9. Rubrics to establich performance criteria for multi-term SOs (a-k) trend analyses.

Case#	Multi-term SO Trend Analysis Results	Review Decision	Recommended Action
1	Forecast after 1 year ≥ **4.0**	*Exceeding Expectations*	No action
2	Forecast after 1 year ≥ **3.0 AND < 4.0** with **> 0 AND < 10%** increase compared to AVERAGE	*Meeting Expectations*	Need comments for SO based on term evaluations and create necessary action items
3	Forecast after 1 year ≥ **3.0 AND < 4.0** with **≥ 10%** increase compared to AVERAGE	*Exceeding Expectations*	No action
4	Forecast after 1 year ≥ **3.0 AND < 4.0** with **< 0%** increase compared to AVERAGE	*Below Expectations*	Need comments for SO based on term evaluations and create action items, review SO change
5	Forecast after 1 year ≥ **2.5 AND < 3.0** with **≥ 10%** increase compared to AVERAGE	*Meeting Expectations*	Need comments for SO based on term evaluations and create necessary action items
6	Forecast after 1 year ≥ **2.5 AND < 3.0** with **≤ 10%** increase compared to AVERAGE	*Below Expectations*	Need comments for SO based on term evaluations and create necessary action items
7	Forecast after 1 year < **2.5**	*Below Expectations*	Review SO change, aggressive actions

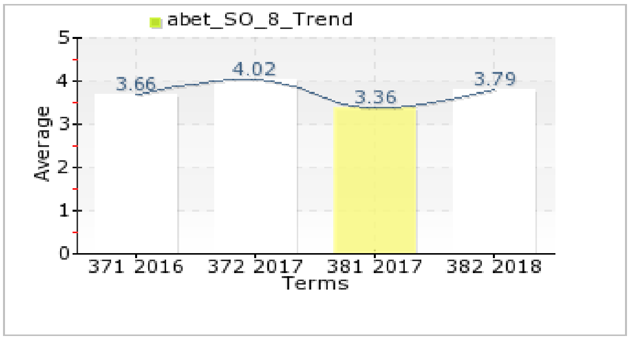


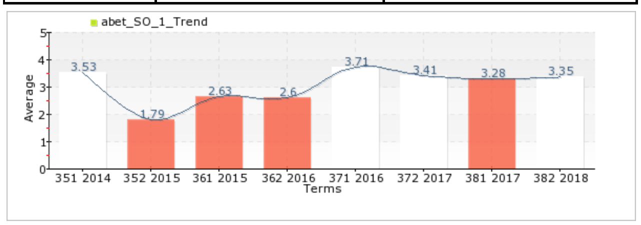
FIGURE 7. *(Continued.)* Consolidated Plot for ME program abet SOs (a-k) multi-term trend analysis.

TABLE 10. Average calculation and next year forecast estimation for SO 'a' (SO_1).

TERM	SNO.	SO_1 Results
351	1	3.53
352	2	1.79
361	3	2.63
362	4	2.6
371	5	3.71
372	6	3.41
381	7	3.28
382	8	3.35
	AVERAGE	**3.04**
	FORECAST (NEXT YEAR)	**3.67**
	% INCREASE	**20.78**

TABLE 11. ME program trend analysis report for SO 'a' SO_1.

Term		
382 2018	Avg	3.35
	Classification	Meeting Expectations
381 2017	Avg	3.28
	Classification	Below Expectations
372 2017	Avg	3.41
	Classification	Meeting Expectations
371 2016	Avg	3.71
	Classification	Meeting Expectations
362 2016	Avg	2.60
	Classification	Below Expectations
361 2015	Avg	2.63
	Classification	Below Expectations
352 2015	Avg	1.79
	Classification	Below Expectations
351 2014	Avg	3.53
	Classification	Meeting Expectations



employ either adhoc and/or limited sampling of assessments and students due to the lack of time and resource constraints for analysis [56], [59]–[63], [76]. EvalTools® embedded assessment technology using FCAR and PVT technology enabled collection of quantitative outcomes data from a large number of direct assessments and all students of associated cohorts [26], [40]–[45], [56]. The findings of Hussain *et al.* (2020) stated that course level outcomes data achieved high statistical power when it was comprehensive, heterogeneous and accurate. Findings of this study indicate that the quantitative outcomes information is valid and reliable since the data is collected using precision learning models, best assessment practice, and assured by having dedicated staff for the quality assurance processes within an automated digital IQMS environment. The aggregated course assessment data is also heterogeneous since it comprehensively represents

TABLE 12. ME program summary of abet SOs (a-k) trend analysis data with review decisions (n = 8).

ABET SOs	Overall Average	Forecast	% Increase	SD	SE	Case Type	Action	Review Date	Review Decision
SO_1 (SO 'a')	3.0375	3.67	120.78	0.64	0.23	3	None	2018-09-03	Exceeding Expectations
SO_2 (SO 'b')	3.90	3.82	98.18	0.40	0.14	4	Very marginal failure the program will continue with existing performance criteria and EAMU scales	2018-09-03	Below Expectations
SO_3 (SO 'c')	3.72	4.60	123.90	0.49	0.22	1	None	2018-09-03	Exceeding Expectations
SO_4 (SO 'd')	4.45	4.65	104.40	0.39	0.20	1	None	2018-09-03	Exceeding Expectations
SO_5 (SO 'e')	2.97	3.80	127.85	0.48	0.17	3	None	2018-09-03	Exceeding Expectations
SO_6 (SO 'f')	3.51	3.88	110.60	0.55	0.25	3	None	2018-09-03	Exceeding Expectations
SO_7 (SO 'g')	3.72	4.96	133.31	0.79	0.35	1	None	2018-09-03	Exceeding Expectations
SO_8 (SO 'h')	3.71	3.56	95.99	0.28	0.14	4	The program needs additional assessments to cover this SO in multiple courses; The performance criteria and EAMU scales will not be modified in the next cycle; This SO is merged with revised ABET SOs	2018-09-03	Below Expectations
SO_9 (SO 'i')	3.97	3.87	97.53	0.50	0.25	4	Very marginal failure. Concentrated focus on research skills and additional assessments are required in multiple courses; performance criteria and EAMU scales shall remain the same for the next cycle	2018-09-03	Below Expectations
SO_10 (SO 'j')	2.64	7.44	281.81	1.36	0.96	1	Need comprehensive assessments; this SO shall be merged with revised ABET SOs;	2018-09-03	Exceeding Expectations
SO_11 (SO 'k')	3.20	3.28	102.68	0.25	0.09	2	Need to concentrate on course level actions; performance criteria and EAMU scales shall remain the same in the next cycle; This SO is merged with revised ABET SOs	2018-09-03	Meeting Expectations
ME Program ABET SOs (a-k) Review Decision				0.56	0.27	Standard Error = 0.27 8 out of 11 SOs Meeting or Exceeding Expectations [60-80%] Final Review Decision: **Meeting Expectations**			

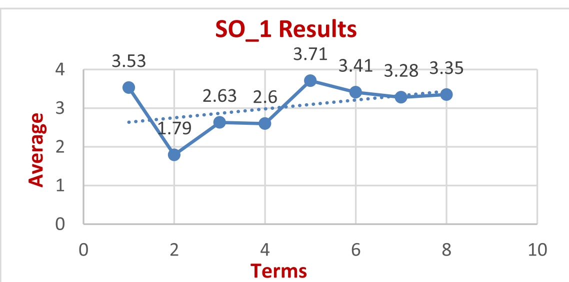


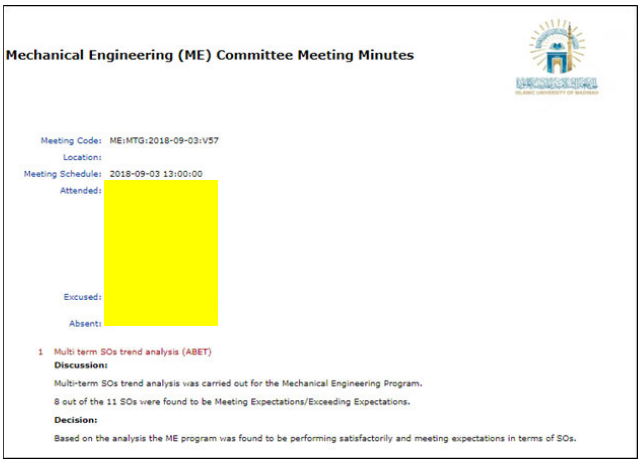
FIGURE 8. Trend analysis based on linear regression for multi-term 351-382 SO 'a' values.

the complete set of cohorts in all assessed courses. The key aspects used by the Faculty of engineering programs to ensure quality standards for accurate assessment and evaluation data include:

a. Implementation of *Bloom's Mastery Learning Model* [75] to develop and administer a curriculum.
b. Adopt the gold standards of Mager's [71] and Adelman's [20] outcomes design principles.
c. Classify COs and specific PIs as per Bloom's three domains and their learning levels and assign electronic indices for tracking and automated EAMU average computations [26].
d. Develop and implement hybrid rubrics for major course learning activities [41,76].
e. Implement unique assessments (where multiple PIs cannot map to a single assessment) [24], [26], [36], [39], [47]–[49], [52], [53], 56], 58], 76].
f. Implement tight scientific constructive alignment of outcomes to assessments using rigorous quality assurance processes [26], [36], [56], [76].

TABLE 13. **CE program summary of abet SOs (a-k) trend analysis data with review decisions (n = 8).**

ABET SOs	Overall Average	Forecast	% Increase	SD	SE	Case Type	Action	Review Date	Review Decision
SO_1 (SO 'a')	3.34	4.35	130.19	0.65	0.23	1	None	2018-09-04	Exceeding Expectations
SO_2 (SO 'b')	3.77	4.99	132.39	0.62	0.22	1	None	2018-09-04	Exceeding Expectations
SO_3 (SO 'c')	3.41	3.64	106.72	0.57	0.23	2	Need to concentrate on course level actions; performance criteria and EAMU scales shall remain the same in the next cycle;	2018-09-04	Meeting Expectations
SO_4 (SO 'd')	4.6175	4.23	91.59	0.15	0.08	1	None	2018-09-04	Exceeding Expectations
SO_5 (SO 'e')	3.03	3.30	108.88	0.34	0.12	2	None	2018-09-04	Meeting Expectations
SO_6 (SO 'f')	3.43	2.74	79.71	0.40	0.20	6	Need to identify additional course topics and assessments; performance criteria and EAMU scales shall remain the same in the next cycle; This SO is merged with revised ABET SOs	2018-09-04	Below Expectations
SO_7 (SO 'g')	3.59	4.27	119.19	0.58	0.24	1	None	2018-09-04	Exceeding Expectations
SO_8 (SO 'h')	2.96	5.63	190.07	1.2	0.49	1	None	2018-09-04	Exceeding Expectations
SO_9 (SO 'i')	4.02	5.78	143.66	0.79	0.46	1	None	2018-09-04	Exceeding Expectations
SO_10 (SO 'j')	3.62	3.83	105.80	0.39	0.23	2	None	2018-09-04	Meeting Expectations
SO_11 (SO 'k')	3.23	3.97	123.06	0.48	0.17	3	None	2018-09-04	Exceeding Expectations
CE Program ABET SOs (a-k) Review Decision				0.56	0.24	Standard Error (SE) = 0.24 10 out of 11 SOs Meeting or Exceeding Expectation >80% Final Review Decision: **Exceeding Expectations**			



Mechanical Engineering (ME) Committee Meeting Minutes

Meeting Code: ME:MTG:2018-09-03:V57
Location:
Meeting Schedule: 2018-09-03 13:00:00
Attended:
Excused:
Absent:

1 Multi term SOs trend analysis (ABET)
Discussion:
Multi-term SOs trend analysis was carried out for the Mechanical Engineering Program.
8 out of the 11 SOs were found to be Meeting Expectations/Exceeding Expectations.
Decision:
Based on the analysis the ME program was found to be performing satisfactorily and meeting expectations in terms of SOs.

FIGURE 9. **ME program meeting ID ME:MTG:2018-09-03:V57 review decision for SOs (a-k) multi-term trend analysis.**

g. Implement course level weighting factors for aggregating outcomes data from a range of types of assessments [26], [36], [40], [56], [76].

In summary, the evaluations of program level SOs, PIs and learning domains conducted at the Faculty of Engineering collected data from all courses, in all levels of the curriculum [26], [40], [41], [56], [76]. Additionally, the High Frequency Weighting Factor Scheme (HFWFS) achieved accurate aggregation of program level skills by assigning scientific weighting based on skill, course levels and frequency of assesments [40]. *Section IV.E* also presents a detailed list of 16 essential elements adopted by the IQMS to ensure high standards of valid and reliable quantitative outcomes assessment data [56], [76]. Therefore, both validity and reliability, and statistical power of quantitative data used for multi-term ABET SOs data were qualified for conducting credible, retrospective impact evaluations of the EE, CE and ME programs.

A. RESEARCH QUESTION 1: WHAT ARE SOME COMMON ISSUES THAT AFFECT THE STATISTICAL POWER OF QUANTITATIVE OUTCOMES DATA COLLECTED BY MANY ENGINEERING PROGRAMS?

Several issues both generic and specific have been listed in various sections of this paper regarding the outcomes data collected by engineering programs for quality and accreditation purposes. Section *I. Introduction* lists generic issues such as sample size, sampling methodology and timeframe, heterogeneity, attrition etc. affecting statistical power of collected data. Section *III.C SOs Data For Manual CQI Systems– A Qualitative Analysis* lists specific issues related to assessment methodology and supporting technology employed thereby affecting the validity and reliability, and statistical power of SOs data collected.

TABLE 14. EE program summary of abet SOs (a-k) trend analysis data with review decisions (n = 8).

ABET SOs	Overall Average	Forecast	% Increase	SD	SE	Case Type	Action	Review Date	Review Decision
SO_1 (SO 'a')	2.46	2.88	117.18	0.38	0.14	5	In general, SO 'a' is improving in overall trend performance so the performance criteria and EAMU levels are satisfactory and the program can continue employing the same performance criteria for this SO.	2018-09-02	Meeting Expectations
SO_2 (SO 'b')	3.77	4.12	109.27	0.49	0.17	1	None	2018-09-02	Exceeding Expectations
SO_3 (SO 'c')	2.96	4.52	152.87	0.88	0.31	1	None	2018-09-02	Exceeding Expectations
SO_4 (SO 'd')	3.56	5.66	158.87	1.76	0.66	1	None	2018-09-02	Exceeding Expectations
SO_5 (SO 'e')	2.65	2.76	104.15	0.42	0.15	6	This SO is modified as per the revised ABET SOs (1-7); Course actions have to be followed; performance criteria and EAMU values are to remain the same.	2018-09-02	Below Expectations
SO_6 (SO 'f')	3.05	4.35	142.61	0.63	0.26	1	None	2018-09-02	Exceeding Expectations
SO_7 (SO 'g')	3.28	5.49	166.87	1.3	0.49	1	None	2018-09-02	Exceeding Expectations
SO_8 (SO 'h')	3.19	5.27	165.60	1.34	0.55	1	None	2018-09-02	Exceeding Expectations
SO_9 (SO 'i')	4.11	3.55	86.39	0.37	0.17	3	The overall average is greater than 4.0 comprehensive assessments to be planned in courses and continued monitoring of this SO in the next cycle. The performance criteria and EAMU values to remain the same.	2018-09-02	Below Expectations
SO_10 (SO 'j')	2.85	2.67	93.68	1.13	0.46	6	Need comprehensive assessments in multiple courses and performance criteria, EAMU values to remain the same.	2018-09-02	Below Expectations
SO_11 (SO 'k')	2.63	3.82	145.07	0.72	0.25	3	None	2018-09-02	Exceeding Expectations
EE Program ABET SOs (a-k) Review Decision				0.86	0.33	Standard Error (SE) 0.33 10 out of 11 SOs Meeting or Exceeding Expectation >80% Final Review Decision: **Exceeding Expectations**			

B. RESEARCH QUESTION 2: WHAT ARE SOME ESSENTIAL ELEMENTS OF BEST ASSESSMENT PRACTICE AND AVAILABLE AUTOMATED DIGITAL TECHNOLOGY THAT HELP ATTAIN VALID AND RELIABLE OUTCOMES DATA?

Section *IV. Theoretical, Conceptual and Practical Frameworks* provides an elaborate discussion on authentic OBE theoretical frameworks followed by induced conceptual frameworks from which models and methods of best assessment practice can be derived. The OAS of EvalTools ® implements the ABET assessment model by aligning COs, with PIs and eventually with the program SOs. Additionally, the PIs are also classified as per affective, cognitive and psychomotor domains of Bloom's learning model which is adopted by both Washington Accord and ABET. Finally, Section *IV.E. Practical Framework —— Summary of Digital Technology and Assessment Methodology* summarized all the essential elements for assessment and described the digital technology that helped to attain valid and reliable outcomes data.

C. RESEARCH QUESTION 3: CAN MULTI-YEAR SOS DATA BE USED TO CONDUCT CREDIBLE IMPACT EVALUATIONS? IF SO, WHAT ARE SOME ESSENTIAL REQUIREMENTS TO ENSURE CREDIBILITY OF EVALUATIONS?

Yes. Multi-term SOs data was used for conducting credible impact evaluations. But, several aspects of authentic OBE assessment methodology have to be incorporated into the

TABLE 15. ME, CE and EE programs' summary of abet SOs (a-k) aggregate values and trend analysis data.

Program	SOs Aggregate Values	SOs Trend Analyses	Comments	Actions
ME	8 out of 11 SOs (a-k) performances just stabilized to aggregate values with *Meeting Expectations* results in the last few terms towards 382 excepting for SO 'k'	8 out of the 11 SOs trends were positive with reasonable multi-term coverage excepting for SOs 'b', 'h' and 'i'	1. If *Meeting* or *Exceeding Expectations* results were observed in multiple terms for any of the SOs, then the minimum performance criteria would have been raised to increase the performance standards. 2. Faculty feedback also indicated acceptable assessment and evaluation data/processes for all SOs except SOs 'b', 'h' and 'i'	**Based on SOs Aggregate Values Results and Comments #1:** No modifications required to performance criteria **Based on SOs Trend Analyses Results and Comments #2:** No modifications required to language of SOs **Transition to revised 7 ABET SOs was reinforced in the summer of 2018**
CE	10 out of 11 SOs (a-k) performances just stabilized to aggregate values with *Meeting Expectations* results in the last few terms towards 382 excepting for SO 'c'	10 out of the 11 SOs trends were positive with reasonable multi-term coverage excepting for SO 'f'	1. If *Meeting* or *Exceeding Expectations* results were observed in multiple terms for any of the SOs, then the minimum performance criteria would have been raised to increase the performance standards. 2. Faculty feedback also indicated acceptable assessment and evaluation data/processes for all SOs except SOs 'c', and 'f'	**Based on SOs Aggregate Values Results and Comments #1:** No modifications required to performance criteria **Based on SOs Trend Analyses Results and Comments #2:** No modifications required to language of SOs **Transition to revised 7 ABET SOs was reinforced in the summer of 2018**
EE	8 out of 11 SOs (a-k) performances just stabilized to aggregate values with *Meeting Expectations* results in the last few terms towards 382 excepting for SOs 'a', 'e' and 'j'	8 out of the 11 SOs trends were positive with reasonable multi-term coverage excepting for SOs 'e', 'i' and 'j'	1. If *Meeting* or *Exceeding Expectations* results were observed in multiple terms for any of the SOs, then the minimum performance criteria would have been raised to increase the performance standards. 2. Faculty feedback also indicated acceptable assessment and evaluation data/processes for all SOs except SOs 'a', 'e', 'i' and 'j'	**Based on SOs Aggregate Values Results and Comments #1:** No modifications required to performance criteria **Based on SOs Trend Analyses Results and Comments #2:** No modifications required to language of SOs **Transition to revised 7 ABET SOs was reinforced in the summer of 2018**

data collection and reporting processes. Sections *IV.A, IV.B* and *IV.C* provide required information to engineering programs for practical implementation of such practice. However, as clearly highlighted in the literature review of this study, manual CQI systems are severely limited for implementing authentic assessment practices since the data collection processes are time consuming, making them unsustainable. Therefore, as suggested in section *IV.D,* web-based software and embedded assessment technology such as that of *EvalTools* ® and *FCAR + specific/generic PIs methodology* offered automated data collection features for sustainable reporting of accurate outcomes data for both quality and accreditation, and impact evaluation purposes [56], [76]. This method was shown to be sustainable since faculty members spend just 5-8 hours additional time per course and have implemented these processes systematically and seamlessly since Fall 2014 [56], [76]. Several essential elements, such as those mentioned in section *IV.E*,were implemented to ensure the multi-term SOs data attained a high level of statistical power. A couple of million documents of evidentiary data in the form of course materials, student work and CQI information was made available on a cloud based environment. ABET evaluators were provided access to this display material using *EvalTools* ® *Remote Evaluator Module* resulting in a very successful 6 years full accreditation in 2020 listing just strengths without any deficiency, concern or weakness. The application of rubrics for linking performance criteria (using regression analysis) to the trend analyses for Sos, counteracted any need for control or comparison groups thereby providing an effective and practically feasible alternative for conducting credible impact evaluations.

VIII. LIMITATIONS

In this study, we focused on a non-experimental approach for impact evaluations using regression methods and rubrics without explicit comparison groups. The scope of this research just covered one PDCA quality cycle Q5 with multi-term SOs review. But, as stated by Onwuegbuzie and Hitchcock (2017), and White and Raitzer (2017), impact evaluations should also incorporate mixed methods approaches for each phase to thoroughly address the required rigor of credible evaluations [49], [73]. The context, construct, causal links of the process, their underlying assumptions and meta-analyses of both product and process should be tested thoroughly. Future research will entail a comprehensive and detailed study of each of the 6 PDCA quality cycles that include all the processes and aspects of the IQMS implemented in these Engineering programs by applying a comprehensive meta-framework proposed by Onwuegbuzie and Hitchcock (2017) [49].

IX. CONCLUSION

Student outcomes are the internationally accepted quality standards for evaluating accountability and student achievement for engineering programs [1], [11]–[16]. Any evaluation of impact of program interventions in engineering education, especially for quality and accreditation purposes, should focus on attainment and progressive improvement in performance of the SOs. By far, the most challenging aspect of accreditation was implementing traceable CQI with tangible improvements from outcomes assessment results [19], [21]–[24], [26], [30], [31], [34]–[41], [44], [45], [54]. Fergus (2012), who was the chair of the ABET Engineering Accreditation Commission, emphasized the need for limiting the sampling for outcomes assessment to make it manageable for manual CQI processes [19]. However, the tradeoff between quality and the amount and type of outcomes data is impractical to achieve manually, since sampling models, frequency and methods of collection are critical requirements that have to be designed carefully to achieve heterogeneous and accurate data. According to authentic OBE theory and the opinions of assessment and quality experts referred to in the introduction to this paper, the two aspects related to data are interchangeable. Sufficient amounts of accurate data have to be sampled appropriately, collected using precision methods and evaluated accurately [76]. When outcomes data is not collected in all courses, using multiple assessments, at various phases of the curriculum, and for all students, then engineering programs cannot attain real-time improvement since they do not have sufficient information to accurately identify failures for any given student, course or assessment. Any CQI model which does not solve problems on a real-time basis but relies on a deferment plan, does not satisfy the requirements of CQI at all. Therefore, manual CQI systems adopt program-centered models to fulfill minimal accreditation standards and do not address the urgent learning needs of current students. Unfortunately, as mentioned in the literature review of this study, manual CQI systems present several issues related to validity and reliability, and statistical power of the SOs data collected. Therefore, engineering programs that employ obsolete assessment methodology and manual CQI systems are forced to employ other means for collecting the necessary data for evaluations [56], [76]. Consequently, programs end up spending additional time and resources to develop and execute plans for credible impact evaluations that may include independent activities and not related to the time consuming activities already completed to ensure quality. The authentic OBE frameworks and digital solutions presented in this study provide a guide for programs on practical measures that can be adopted to avoid reinventing the wheel when it comes to quality and accreditation efforts or conducting credible impact evaluations. The quality of SOs data collected for accreditation achieved significantly higher statistical power and accuracy that enabled credible impact evaluations.

Onwuegbuzie and Hitchcock (2017) stated that programs should conduct a rigorous evaluation of impact, either prospectively or retrospectively by using a credible counterfactual to compare outcomes to those without application of the intervention under observation [49]. They suggested identifying such control or comparison groups to avoid confounding factors, selection issues, and misinformation leading to a spurious relationship between the intervention and its outcome [49]. The EE, CE and ME programs were assigned stipulated amounts from institutional budgetary allocations to cover costs for implementing CQI processes, preparation of self-study, procurement of required infrastructure and other resources to manage the ABET accreditation visit in 2019. Institutional budgetary allocations did not officially recognize the requirement for any additional spending on control or comparison groups functioning as counterfactuals due to difficulty in maintaining an anamolous observatory cohort in a mainstream educational setting and the lack of any mandate from international engineering accreditation agencies like ABET or the IEA's Washington Accord [1], [11], [16]. Therefore, instead of using counterfactuals, multi-term SOs were evaluated using regression trend analyses to confirm the impact of implementation of the IQMS at the CE, ME and EE programs of the Faculty of Engineering. The multi-term SOs data served as a better option to study impact of interventions since this data was quantitative, heterogeneous, valid and reliable. This was due to being collected from all students using direct assessments and state of the art digital technology, under the strict monitoring and supervision of dedicated staff, and following world class assessment practices. Multiple issues regarding management of control and/or comparison groups and strict regulation of interference conditions, or spurious relationships with interventions were totally avoided. Multi-term executive summary reports showed detailed reflections, corrective actions; and the CIMS system recorded improvements with thousands of actions and evidentiary CQI documentation [56], [76]. Multi-term SOs trend analyses with forecasted results showing improved SOs performances reinforced the decision of program committee reviewers, EAC members and other stakeholders to qualify the ME, CE and EE programs as *Meeting* or *Exceeding Expectations* in regards to attainment of SOs. In conclusion, the findings of this study provided evidence of a viable digital solution based on authentic OBE assessment methodology to collect accurate multi-term SOs data for conducting credible impact evaluations, without incurring additional resources other than those needed for quality and accreditation efforts.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

FUNDING

There is no funding for this project.

ACKNOWLEDGMENT

This research was based on the results of a rigorous five-year program for the implementation of a comprehensive Outcomes Based Education model involving the curriculum, teaching, learning, advising, and other academic and quality assurance processes for the CE, ME, and EE engineering departments with the Faculty of Engineering, Islamic University of Madinah. The program efforts were directly led by the corresponding author and three of the coauthors who at the time were the Director of the Quality and Accreditation Office at the Faculty of Engineering, Islamic University, and ABET coordinators for the CE, ME, and EE departments, respectively. The authors would like to thank the faculty members for their cooperation and support in completing the necessary quality assurance and academic teaching processes that enabled the collection of the necessary results.

REFERENCES

[1] (2020). *International Engineerng Alliance (IEA), Washington Accord Signatories*. [Online]. Available: https://www.ieagreements.org/accords/washington/signatories/

[2] W. Spady, ''Organizing for results: The basis of authentic restructuring and reform,'' *Educ. Leadership*, vol. 46, no. 7, pp. 4–8, Oct. 1988.

[3] W. Spady and K. J. Marshall, ''Beyond traditional outcome-based education,'' *Educ. Leadership*, vol. 49, no. 71, pp. 67–72, Oct. 1991.

[4] W. Spady. (2020). *Outcome-Based Education's Empowering Essence. Mason Works Press, Boulder, Colorado*. [Online]. Available: http://williamspady.com/index.php/products/

[5] W. Spady, ''Choosing outcomes of significance,'' *Educ. Leadership*, vol. 51, no. 5, pp. 18–23, 1994.

[6] W. Spady, *Outcome-Based Education: Critical Issues and Answers*. Arlington, VA, USA: American Association of School Administrators, 1994.

[7] J. Moon. (2000). *Linking levels, learning outcomes and assessment criteria. Bologna Process.-European Higher Education Area*. [Online]. Available: http://aic.lv/ace/ace_disk/Bologna/Bol_semin/Edinburgh/J_Moon_backgrP.pdf

[8] R. Killen, *Teaching Strategies for Outcome Based Education*, 2nd ed. Cape Town, South Africa: Juta, & Co, 2007.

[9] R. M. Harden, ''Developments in outcome-based education,'' *Med. Teacher*, vol. 24, no. 2, pp. 117–120, Jan. 2002, doi: 10.1080/01421590220120669.

[10] R. M. Harden, ''Outcome-based education: The future is today,'' *Med. Teacher*, vol. 29, no. 7, pp. 625–629, Jan. 2007, doi: 10.1080/01421590701729930.

[11] (2020). *Accreditation Board Eng. Technol. (ABET), USA*. Accreditation Criteria. www.abet.org. [Online]. Available: http://www.abet.org/accreditation/accreditation-criteria/

[12] (2020). *Canadian Engineering Accreditaton Board (CEAB)*. Canada. Accreditation Resources and Criteria. [Online]. Available: https://engineerscanada.ca/accreditation/accreditation-resources

[13] (2020). *Saudi Arabian National Center for Academic Accreditation and Evaluation (NCAAA)*, Saudi Arabia. [Online]. Available: https://etec.gov.sa/en/About/Centers/Pages/Accreditation.aspx

[14] *EUR-ACE. Framework and Accreditation System Awarded by an Authorised Agency to a HEI (Higher Education Institution)*. Accessed: Jun. 17, 2020. [Online]. Available: https://www.enaee.eu/eur-ace-system/

[15] *Accreditation Documents and Criteria*, National Board of Accreditation (NBA), New Delhi, India, 2020. .

[16] International Engineering Alliance (IEA). 2020. *Graduate Attributes and Professional Competencies*. [Online]. Available: https://www.ieagreements.org/assets/Uploads/Documents/Policy/Graduate-Attributes-and-Professional-Competencies.pdf

[17] N. Gannon-Slater, S. Ikenberry, N. Jankowski, and G. Kuh, *Institutional Assessment Practices Across Accreditation Regions*. Urbana, IL, USA: National Institute of Learning Outcomes Assessment (NILOA), 2014. [Online]. Available: www.learningoutcomeassessment.org/documents/Accreditation%20report.pdf

[18] S. Provezis, *Regional Accreditation and Student Learning Outcomes: Mapping the Territory*. Urbana, IL, USA, National Institute of Learning Outcomes Assessment (NILOA), 2010. [Online]. Available: www.learningoutcomeassessment.org/documents/Provezis.pdf and https://files.eric.ed.gov/fulltext/ED544355.pdf

[19] J. Fergus, ''Program Improvement through Accreditation,'' *J. Minerals, Met. Mater. Soc.*, vol. 64, no. 1, p. 3, 2012, doi: 10.1007/s11837-012-0260-1.

[20] C. Adelman, *To Imagine a Verb: The Language and Syntax of Learning Outcomes Statements*. Phoenix, AZ, USA: National Institute of Learning Outcomes Assessment (NILOA), 2015. [Online]. Available: http://learningoutcomesassessment.org/documents/Occasional_Paper_24.pdf

[21] S. K. Dew, M. Lavoie, and A. Snelgrove, ''An engineering accreditation management system,'' in *Proc. Can. Eng. Educ. Assoc. Paper presented 2nd Conf. Can. Eng. Educ. Assoc.*, Jun. 2011, pp. 1–5, doi: 10.24908/pceea.v0i0.3577.

[22] E. Essa, A. Dittrich, S. Dascalu, and F. C. Harris, ''ACAT: A Web-based software tool to facilitate course assessment for ABET accreditation,'' presented at the 7th Int. Conf. Inf. Technol., New Gener., Las Vegas, NV, USA, Apr. 2010. [Online]. Available: http://www.cse.unr.edu/~fredh/papers/conf/092-aawbsttfcafaa/paper.pdf

[23] A. W. Mohammad and A. Zaharim, ''Programme outcomes assessment models in engineering faculties,'' *Asian Social Sci.*, vol. 8, no. 16, p. 115, Nov. 2012, doi: 10.5539/ass.v8n16p115.

[24] Y. Kalaani and R. J. Haddad, ''Continuous improvement in the assessment process of engineering programs,'' in *Proc. ASEE South East Section Conf.*, Mar. 2014, pp. 1–11.

[25] M. L. Cruz, G. N. Saunders-Smits, and P. Groen, ''Evaluation of competency methods in engineering education: A systematic review,'' *Eur. J. Eng. Educ.*, vol. 45, no. 5, pp. 729–757, Sep. 2020, doi: 10.1080/03043797.2019.1671810.

[26] W. Hussain, F. Mak, and M. F. Addas, ''Engineering program evaluations based on automated measurement of performance indicators data classified into cognitive, affective, and psychomotor learning domains of the revised Bloom's taxonomy,'' in *Proc. ASEE 123rd Annu. Conf. Expo.*, New Orleans, LA, USA, Jun. 2016, pp. 1–40.

[27] P. Black and D. William, ''Inside the black box: Raising standards through classroom assessment,'' *Phi Delta Kappan*, vol. 80, p. 139, Nov. 1998.

[28] Univ. New South Wales (UNSW), Kensington, NSW, Australia. *Assessment Toolkit: Aligning Assessment With Outcomes*. Accessed: May 5, 2019. [Online]. Available: https://teaching.unsw.edu.au/printpdf/531

[29] *Taxonomy of Educational Objectives: The Affective Domain*, McKay, New York, NY, USA, 1956.

[30] P. F. Mead and M. M. Bennett, ''Practical framework for Bloom's based teaching and assessment of engineering outcomes,'' in *Proc. Educ. Training Opt. Photon.*, Jun. 2009, pp. 1–10, doi: 10.1364/ETOP.2009.ETB3.

[31] P. Mead, T. Turnquest, and S. Wallace, ''Work in progress: Practical framework for engineering outcomes based teaching and assessment—A catalyst for the creation of faculty learning communities,'' in *Proc. Frontiers Education. 36th Annu. Conf.*, 2006, pp. 19–20, doi: 10.1109/FIE.2006.322414.

[32] L. F. Gardiner, ''Assessment essentials: Planning, implementing, and improving assessment in higher education (review),'' *J. Higher Educ.*, vol. 73, no. 2, pp. 302–305, 2002.

[33] M. F. Wyne, ''Ensure program quality: Assessment a necessity,'' in *Proc. IEEE Educon Conf.*, Apr. 2010, pp. 1621–1630.

[34] V. S. Kumaran and T. E. Lindquist, ''Web-based course information system supporting accreditation,'' in *Proc. 37th Annu. Frontiers Educ. Conf. Global Eng., Knowl. Without Borders, Opportunities Without Passports*, Oct. 2007, pp. 1–6. [Online]. Available: http://fieconference.org/fie2007/papers/1621.pdf

[35] M. Eltayeb, M. Fong, and O. Soysal, ''Work in progress: Engaging faculty for program improvement via EvalTools: A new software model,'' in *Proc. Frontiers Educ. Conf.*, Oct. 2012, pp. 1–6, doi: 10.1109/FIE.2012.6462443.

[36] W. Hussain and M. F. Addas, "A digital integrated quality management system for automated assessmentof QIYAS standardized learning outcomes," in *Proc. 2nd Int. Conf. Outcomes Assessment (ICA)*, QIYAS, Riyadh, KSA, 2015, pp. 603–654.
[37] W. Ibrahim, Y. Atif, K. Shuaib, and D. Sampson, "A Web-based course assessment tool with direct mapping to student outcomes," *Educ. Technol. Soc.*, vol. 18, no. 2, pp. 46–59, 2015.
[38] K. P. Suseel, "Automating outcomes based assessment," in *Proc. ACM Conf.*, Jan. 2005. [Online]. Available: https://citeseerx.ist.psu.edu/viewdoc/download? doi: 10.1.1.199.4160&rep=rep1&type=pdf.
[39] W. Hussain and M. F. Addas, *Digitally Automated Assessment of Outcomes Classified Per Bloom's Three Domains and Based on Frequency and Types of Assessments*. Urbana, IL, USA: Univ. Illinois and Indiana University, National Institute for Learning Outcomes Assessment (NILOA), Apr. 2016. [Online]. Available: http://www.learningoutcomesassessment.org/documents/Hussain_Addas_Assessment_in_Practice.pdf
[40] W. Hussain, M. F. Addas, and F. Mak, "Quality improvement with automated engineering program evaluations using performance indicators based on Bloom's 3 domains," in *Proc. IEEE Frontiers Educ. Conf. (FIE)*, Oct. 2016, pp. 1–9.
[41] W. Hussain and W. Spady, "Specific, generic performance indicators and their rubrics for the comprehensive measurement of ABET student outcomes," in *Proc. ASEE Annu. Conf. Expo.*, Jun. 2007, pp. 1–21.
[42] J. McGourty, C. Sebastian, and W. Swart, "Performance measurement and continuous improvement of undergraduate engineering education systems," in *Proc. Frontiers Educ. 27th Annu. Conf., Teach. Learn. Era Change*, Nov. 1997, pp. 1294–1301.
[43] J. McGourty, C. Sebastian, and W. Swart, "Developing a comprehensive assessment program for engineering education*," *J. Eng. Educ.*, vol. 87, no. 4, pp. 355–361, Oct. 1998, doi: 10.1002/j.2168-9830.1998.tb00365.x.
[44] F. Mak and J. Kelly, "Systematic means for identifying and justifying key assignments for effective rules-based program evaluation," in *Proc. IEEE Frontiers Educ. Conf. (FIE)*, Oct. 2010, pp. 1–6.
[45] F. Mak and R. Sundaram, "Integrated FCAR model with traditional rubric-based model to enhance automation of student outcomes evaluation process," in *Proc. ASEE 123rd Annu. Conf. Expo.*, New Orleans, LA, USA, Jun. 2016. [Online]. Available: https://www.asee.org/public/conferences/64/papers/15760/view
[46] S. K. Pallapu. (2005). *Automating Outcomes Based Assessment*. [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.199.4160&rep=rep1&type=pdf
[47] *Information on EvalTools*. Accessed: Jun. 12, 2020. [Online]. Available: http://www.makteam.com
[48] H. Gurocak, L. Chen, D. Kim, and A. Jokar, "Assessment of program outcomes for ABET accreditation," in *Proc. ASEE 116th Annu. Conf. Expo.*, Austin, TX, USA, Jun. 2009. [Online]. Available: https://peer.asee.org/assessment-of-program-outcomes-for-abet-accreditation.pdf
[49] A. J. Onwuegbuzie and J. H. Hitchcock, "A meta-framework for conducting mixed methods impact evaluations: Implications for altering practice and the teaching of evaluation," *Stud. Educ. Eval.*, vol. 53, pp. 55–68, Jun. 2017, doi: 10.1016/J.STUEDUC.2017.02.001.
[50] *When Will We Ever Learn? Improving Lives Through Impact Evaluation*, Evaluation Gap Working Group, Center for Global Development, Washington, DC, USA, 2006. [Online]. Available: http://www.cgdev.org/files/7973_file_WillWeEverLearn.pdf
[51] H. White, "Theory-based impact evaluation: Principles and practice," *J. Develop. Effectiveness*, vol. 1, no. 3, pp. 271–284, Sep. 2009, doi: 10.1080/19439340903114628.
[52] K. Salim, R. Ali, N. Hussain, and H. Haron, "An instrument for measuring the learning outcomes of laboratory work," in *Proc. IETEC Conf.*, Ho Chi Minh City, Vietnam, 2013, pp. 1–17.
[53] R. S. Carriveau, *Connecting the Dots: Developing Student Learning Outcomes and Outcome-Based Assessments*. Sterling, VA, USA: Stylus Publications, 2016.
[54] W. Hussain and W. G. Spady, "Industrial training courses: A challenge during the COVID19 pandemic," in *Proc. IEEE Int. Conf. Teaching, Assessment, Learn. Eng. (TALE)*, Dec. 2020, pp. 189–196.
[55] W. E. Deming, *The New Economics for Industry, Government, and Education*. Boston, MA, USA: MIT Press, 1993, p. 132.
[56] W. Spady, W. Hussain, J. Largo, and F. Uy, *Beyond Outcomes Accreditation*. Manila, Philippines: Rex Publishers, Feb. 2018. [Online]. Available: https://www.rexestore.com/home/1880-beyond-outcomes-accredidationpaper-bound.html
[57] A. Jonsson and G. Svingby, "The use of scoring rubrics: Reliability, validity and educational consequences," *Educ. Res. Rev.*, vol. 2, no. 2, pp. 130–144, Jan. 2007. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1747938X07000188, doi: 10.1016/j.edurev.2007.05.002.
[58] K. R. Gosselin and N. Okamoto, "Improving instruction and assessment via Bloom's taxonomy and descriptive rubrics," in *Proc. ASEE 125th Annu. Conf. Expo.*, Salt Lake City, UT, USA, Jun. 2018. [Online]. Available: https://www.asee.org/public/conferences/106/papers/21425/view
[59] K. N. El and M. M. Bunagan, "Assessment methodologies for ABET accreditation: Success factors and challenges," in *Proc. Int. Conf. Frontiers Educ., Comput. Sci. Comput. Eng. (FECS)*, 2015, p. 116. [Online]. Available: http://worldcomp-proceedings.com/proc/p2015/FEC6208.pdf
[60] D. Alghazzawi and H. Fardoun, "Developing an accreditation process for a computing faculty with focus on the IS program," *J. Case Studies Accreditaton Assessment*, vol. 3, pp. 1–20, Feb. 2014.
[61] Sampling Student Work (2015). *Office of Assessment. Office of the Provost. Santa Clara University*. [Online]. Available: https://www.scu.edu/provost/institutional-effectiveness/assessment/the-assessment-process/assessment-method/sampling-student-work.html
[62] ETAC ABET. (2017). *Draft Statement to Central Washington University Enginering Technology Programs, 'Small Sample Size*. [Online]. Available: http://www.cwu.edu/mission/sites/cts.cwu.edu.mission/files/documents/specialized-accred/etac-abet/met/6_CWU-MET-ETAC-ABET-2017-Draft-Statement-from-ETAC.pdf
[63] A. Adams, *A Program Assessment Guide: Best Practices for Designing Effective Assessment Plans*. Madison, WI, USA: Academic Affairs, Univ. Wisconsin, Wisconsin, Milwaukee, 2019, pp. 39–53. [Online]. Available: https://uwm.edu/academicaffairs/wp-content/uploads/sites/32/2019/04/Guide.pdf
[64] K. P. Cross, *Feedback in the Classroom: Making Assessment Matter*. Washington, DC, USA: American Association for Higher Education Assessment Forum, 1988.
[65] H. G. Herring, III, and G. D. Izard, "Outcomes assessment of accounting majors," *Issues Accounting Educ.*, vol. 7, no. 1, pp. 1–17, 1992.
[66] J. L. Ammons and S. K. Mills, "Course-embedded assessments for evaluating cross-functional integration and improving the teaching-learning process," *Issues Accounting Educ.*, vol. 20, no. 1, pp. 1–19, Feb. 2005.
[67] H. Gerretson and E. Golson, "Synopsis of the use of course-embedded assessment in a medium sized public University's general education program," *J. Gen. Educ.*, vol. 54, no. 2, pp. 139–149, 2005.
[68] J. Estell, J.-D. Yoder, B. Morrison, and F. Mak, "Improving upon best practices: FCAR 2.0," in *Proc. ASEE Annu. Conf. Expo.*, Jun. 2012, pp. 725–755.
[69] C. Liu and L. Chen, "Selective and objective assessment calculation and automation," in *Proc. 50th Annu. Southeast Regional Conf.*, Tuscaloosa, AL, USA, Mar. 2012, pp. 192–196.
[70] R. L. Miller and B. M. Olds, "Performance assessment of EC-2000 student outcomes in the unit operations laboratory," in *Proc. ASEE Annu. Conf.*, 1999, pp. 414–417.
[71] R. F. Mager, *Preparing Instructional Objectives: A Critical Tool in the Development of Effective Instruction*, 2nd ed. Belmont, CA, USA: Lake Publishing, 1984.
[72] W. Hussain, W. Spady, and F. Mak, "Outcome based education—Student's outcomes data for implementation of effective developmental advising using digital advising systems, higher education pedagogies," *Routledege, Taylor Francis J.*, to be published.
[73] H. White and D. Raitzer, *Impact Evaluation of Development Interventions—A Practical Guide*. Manila, Philippines: Asian Development Bank, 2017, doi: 10.22617/TCS179188-2.
[74] M. Song and R. Herman, "Critical issues and common pitfalls in designing and conducting impact studies in education: Lessons learned from the what works clearinghouse (phase I)," *Educ. Eval. Policy Anal.*, vol. 32, no. 3, pp. 351–371, Sep. 2010. [Online]. Available: http://www.jstor.org/stable/40963082
[75] B. S. Bloom, "Learning for mastery," UCLA CSIP Evaluation Comment, Regional Education Laboratory for the Carolinas and Virginia, Durham, NC, USA, Mar. 1968. [Online]. Available: https://eric.ed.gov/?id=ED053419
[76] W. Hussain, W. G. Spady, M. T. Naqash, S. Z. Khan, B. A. Khawaja, and L. Conner, "ABET accreditation during and after COVID19—Navigating the digital age," *IEEE Access*, vol. 8, pp. 218997–219046, 2020, doi: 10.1109/ACCESS.2020.3041736.