International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

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MATHEMATICAL MODELS FOR EVALUATING PROGRAM AND COURSE LEARNING OUTCOMES IN HIGHER EDUCATION

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ARTICLEINFO

Article history:
Received 12 November 2018
Received in revised form 12 February 2019
Accepted 18 February 2019
Available online
25 February 2019

Keywords:
Program learning outcomes (PLO); CLO; KPI; Key Performance Indicators; Learning Assessment Model.

ABSTRACT

At present, most of the Universities concentrates on assessing the programming learning outcome. These programs learning outcomes (PLO) are defined/fixed by the accreditation agencies and are mapped with the course learning outcome (CLO). In a micro level, key performance indicators (KPIs) are defined for each program learning outcomes. The role of a faculty member is very important in this stage in evaluation and assessment. The faculty member sets the assessment tools based on the course learning outcomes and the associated key performance indicators. Evaluation is carried out by the faculty member based on the rubrics associated with the performance indicator. The evaluation process should be more transparent and to provide a clear picture of the student position in the class. The need for developing a suitable mathematical model to record the marks at micro level and assess the outcomes must be considered by the Universities in order to strengthen the assessment process. This research paper deals with developing mathematical models to evaluate the average scores of the programming learning outcomes and course learning outcomes.

1. INTRODUCTION

The assessment and evaluation process is very vital in any education system. The courses in the higher educational level are evaluated against the learning outcome. This learning outcome are referred as course learning outcome (CLO). This course learning outcomes are then mapped with the program learning outcomes. The higher educational institutions in the Kingdom of Saudi Arabia also uses the Key Performance Indicators (KPI). These KPIs are at the micro level and are mapped with the course learning outcomes. The teacher sets the question paper for a chosen course based on the KPIs and CLOs. After the

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evaluation, the marks are entered against the KPIs to calculate the average score for each outcome. At present, there is no uniform / standard model available with the Universities to calculate the average score. Most of the Universities uses custom build software or an Excel sheet to enter the marks and calculate the average score. The proposed research deals about development mathematical models for calculating the score for evaluating KPIs, CLOS and program learning outcome. This model is tested with two courses with the College of Computer and Information Sciences of Majmaah University of Kingdom of Saudi Arabia. The developed mathematical model with the test cases for two courses are presented to demonstrate the application of the proposed approach. The Developed mathematical models improve the quality of assessment and evaluation. The results are presented at the end of the paper by comparing with the existing approaches presently used to calculate the average scores.

The main objectives of the paper are provided below

- Study of existing evaluation methods and criteria
- Study the role of mathematical model in assessment and evaluation
- Developing a suitable mathematical model to assess the programming learning outcomes and course learning outcome
- Testing the developed model
- Implementation of the tested model in colleges / Universities

2. REVIEW OF THE LITERATURE

The literature review had been carried out in various aspects by considering the scope of the project.

Love et al. [1] presents a new model that concentrates more on the problem-solving approach rather that the traditional approach such as using the classrooms etc., The author proposes a STEM model which can be used in science, technology, engineering, and mathematics fields. This is data-driven model presented by the author. The author has carried out only little research in assessing the potential effects of student learning outcomes using the STEM approach.

Phillips [2] analyses the work of previous images of mathematical modelling are reviewed and compared. These previous images are used to develop a set of definitions for the different components of modelling. To develop an improved image of modelling for teaching and learning, new systems are developed in the mathematical modelling process. Furthermore, new processes between all the systems are examined. The new systems and processes are included in a new image to acknowledge and recognize important processes in the classroom. The new theory and image are then used to represent and reconcile past images of modelling.

Mason and Dragovich [3] presents a coursework-based assessment methodology. The author implements and analyses this methodology using a database system, and a least square analysis. The methodology is then presented by analysing the data in an engineering program over a four-year period. The results of this assessment are clearly discussed in this paper.

Harmanani [4] presents a bottom-up outcome-based assessment approach. This approach facilitates the faculty members participation and simplifies the assessment and reporting processes in the evaluation. The author has implemented the proposed approach for the successful accreditation of a computer science program. This approach can be easily applied to any higher education program.

Springer et al. [5] demonstrates that various forms of small-group learning are effective in promoting greater academic achievement. The author presents the important attitudes toward learning. The author presents a SMET approach, which can be used to, to group of students learning science, mathematics, engineering, and technology courses of the department.

Hajj-Hassan et al. [6] highlights the Biomedical Engineering program students learning outcomes assessment approach. The results in this paper discusses the data collection in line with the best practices, usage of key performance indicators. The overall objective of this paper is to help the academic departments to improve the quality in assessment and evaluation.

Imam and Tasadduq presents a simple formula that can be used to convert CLO-based assessment scores to SO-based scored through the CLO-SO mapping. The author presents a software package namely "CLOSO" which is used to implement the formula. This software automates the evaluation of CLO scores and SO scores which is used to improve the quality of assessment data. This software also helps the faculty members to save the time [7].

Bareduan et al. [8] presents an application of continuous quality improvement process. The author uses this process for an engineering course. The author considers the performance measures such as course learning outcomes (CLO), CLO attainment levels and overall course grades. The author also presents a pareto diagram which is used to analyse the CLO attainment levels data resulting from tests, assignments and final exam marks.

Freeman et al. proposes and tests a hypothesis, this is used to maximize learning and course performance. The authors analysed 225 studies that reported data on examination scores, the author has tested the model with the students learning science, mathematics, engineering, and technology courses of the department [9].

Huang and Fang compares four types of mathematical models. The developed mathematical models are used to predict student academic performance in a course (engineering dynamics). This course is considered by the author due to a high-enrolment and it is a core course that many engineering undergraduates are required to take. The author uses multiple linear regression model, the multilayer perception network model, the radial basis function network model, and the support vector machine model in the proposed mathematical model. The author integrates the proposed model with a learning management system. The learning management system enhances the learning outcomes to meet the expectations [10].

The learning management system also enhance the learning outcomes to meet the expectations [11]. Marks et al (study the uses of technology in higher education for the course evaluation for the several parameters e.g. quality of questions, grouping of the course and course learning outcomes at the college and university level [12]. George et al. develop a software tool to calculate the KPI for the course evaluation and ABET criterion [13].

It is clear from the above-reviewed literature that there is no standard mathematical available to evaluate the average scores as proposed in this research work. Also, the few existing mathematical models are not suited to be used with the educational institutions.

3. METHODOLOGY

In order to meet the defined first objective, a detailed study was carried out on existing evaluation. The study focused on six colleges in the Majmaah University. It is noted that all the colleges have their custom build software or a sheet to calculate the score. There is no uniformity in the calculation of the average evaluation score. This provides strong justification to the authors to proceed with defined problem. At present, the scope is limited inside the college. Efforts will be taken to extend the scope after successful validation. The whole assessment process is presented in Figure 1.

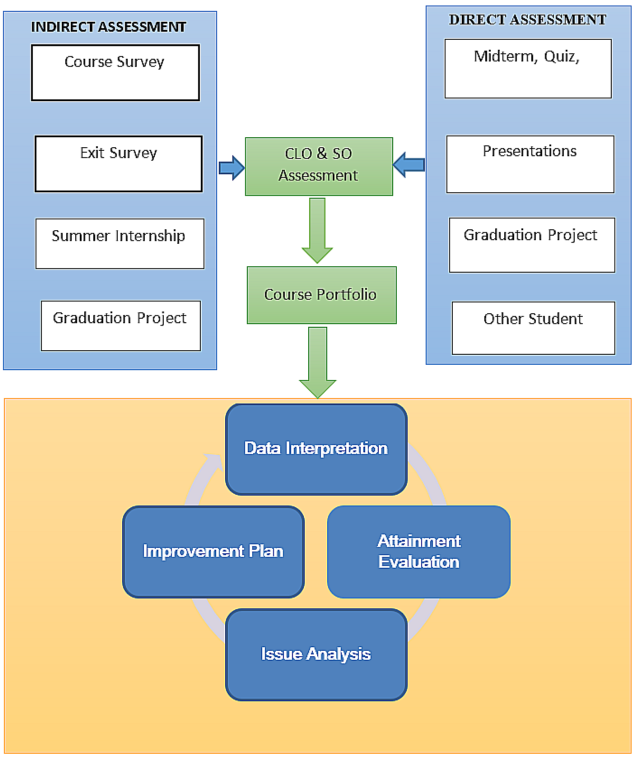

Figure 1: Assessment and Evaluation Processes

Also, as stated in second objective, the proposal of using standard Mathematical model leads to a creation of a new standard. Once the standard validation is successful in all aspects, this helps the Universities to follow and establish common acceptance criteria among all the colleges.

For the objective three, this research aims to develop a suitable mathematical model for the following parameters used in assessment and evaluation

- Key Performance Indicators (KPIs)
- Course Learning Outcomes (CLOs)
- Program Learning Outcomes (PLOs)

3.1 Assessment Process

The assessment and evaluation of SOs of an individual course during the semester based on data collection is explained in detail. Table 1, the various attainment level based on the marks scored by the students has been given.

Table 1: Assessment Attainment Level

Exceeds Expectations (EE)	Meets Expectations (ME)	Progressing Towards Expectations (PE)	Does Not Meet Expectations (DNME)
>=80% or more of students are achieving the satisfactory level or above	>=70% and <80% of students are achieving the satisfactory level or above	>=60% & <70% of students are achieving the satisfactory level or above	< 60% of students are not achieving the satisfactory level

4. DATA COLLECTION

The direct assessment is evidence of student outcome. It is tangible, visible, measurable and tends to be more compelling evidence of exactly what students have and does not learned. The evidence of students' performance to determine what they've learned is available in the course portfolio.

Indirect assessment evidences tend to be composed of proxy signs that students are probably learning. An example of indirect evidence is a survey through which asking students their self-report that what they have learned. This is evidence that students probably are learning what they report to have learned, but it is not as compelling as a faculty member looking at students' work. It is not uncommon in students' self-reports to either inflate or undervalue what they have learned.

Course assessment report is a consolidated evidence by the instructor of each and individual section. It contains the data collected from direct and indirect assessments, which were practiced during semester. The information is gathered using several instruments at regular intervals. For example, an exit survey is a data collection instrument that is used to gather information about the graduating students' opinion to measure the SOs achievement. These instruments are described in detail at later sections.

Data Preparation: The data preparation involves validation and transformation to make it ready for use in evaluation of SOs. For example, the paper-based survey data is converted to electronic format. The illegible, incomplete, erroneous or duplicate submissions are discarded whenever necessary.

4.1 EVALUATION PROCESSES

Data Interpretation: Metrics are used to summarize data and its interpretation based on the points of interest. For example, the survey responses are used to calculate weighted averages scored of SOs.

Attainment Evaluation: The attainment of evaluation for all the SOs are measured in this step. For example, the verification of the SO achievement from various data sources with reference to the threshold values (EE-Exceeding Expectation, ME-Meeting Expectation, PE-Progressing towards Expectation & DNME-Does Not Meet Expectation) are carried out.

Issue Analysis: Wherever the evaluation of targeted SOs are not achieved, an issue based deeper analysis is conducted. For example, reviewing faculty course assessment reports, discussing with faculty and students to determine underlying issues for poor achievement.

Improvement plan: An action plan is developed to remedy the identified issues and recommended implementation over the issue.

4.2 MATHEMATICAL MODEL FOR KPIs

A Key Performance Indicator is a quantitative value that demonstrates how effectively a course is achieving the objectives. The Universities used the KPIs at multiple levels to evaluate their performance. The KPIs provides how well the course is progressing across the semesters/years. The KPIs vary for each course and program across a University. The following are the important properties of the KPIs

- Well defined
- Measurable
- Important in achieving the objective
- Aligned with the objective of the department

In the Course level, the KPIs are defined for each PLOs. Few example KPIs for the PLO *"An ability to apply knowledge of computing and mathematics appropriate to the discipline"* is listed below

a) Ability to apply knowledge of mathematics (e.g., statistics, probability, discrete mathematics)
b) Ability to solve and implement a programming problem from a given computation model using procedural and/or object-oriented programming approach
c) Ability to use algorithmic knowledge to present a feasible algorithmic solution to a problem
d) Ability to apply knowledge of computing

By keeping these justifications, this research paper proposes mathematical model to calculate the score of a KPI which is presented as detailed below.

Let us consider as follows. The total size of the class

$$\boldsymbol{N} = \boldsymbol{n_1} + \boldsymbol{n_2} + \boldsymbol{n_3} \qquad (1),$$

where $\boldsymbol{n_1}$ is the number of students who scored above 80% marks in the question pertaining to assigned KPI., $\boldsymbol{n_2}$ is the number of students who scored above 60% and less than 80% marks in the question pertaining to assigned KPI, $\boldsymbol{n_3}$ is the number of students who scored less than 60% marks in the question pertaining to assigned KPI.

KPI Results in Percentage for m^{th} KPI is denoted by K_m. KPI has been calculated based on the marks score in the assessments. The techniques based on the weightage of student's category e. g meet expectation, below expectation or above the expectation. One can choose the category as per the requirement of the criteria of assessments.

$$K_m = \frac{\sum_{i=1}^{l} w_i n_i}{w_{imax} N} \quad (2),$$

where w_i is the weight assign for category of the students who score in i^{th} type of category types based on the performance and $w_{imax} = \max(w_1, w_2, w_3, \ldots w_i \ldots, w_l)$. The weightage can be obtained after validation with the average percentage obtained by the whole course.

4.3 MATHEMATICAL MODEL FOR THE PLOs

The program learning outcomes are the statements that specify what the students will know or will be able to do after completing a program. These outcomes are indicated using knowledge, cognitive skills, communication skills, information technology skills etc. The important characteristics of the PLOs are

- Measurable
- To be demonstrated
- Observable

All the programs (BS, MS etc.,) in the Universities are provided with the PLOs. Mostly, these PLOs are defined by the accreditation agencies such as ABET, NCAAA etc., Few example PLOs are listed below

1) An ability to apply knowledge of computing and mathematics appropriate to the discipline.
2) An ability to analyze a problem and identify and define the computing requirements appropriate to its solution.
3) An ability to use current techniques, skills, and tools necessary for computing practices

By calculating the average score of the PLOs, the Universities/departments knows the present performance and take remedial actions to further strengthen the assessment and evaluation process. This paper proposes the following mathematical model to be used to calculate the average score for each PLOs.

Let us consider as follows. The students learning outcome for a to k (the ABET LO) assessed by the

$$S_j = \frac{1}{p} \sum_{i=1}^{p} K_i = \frac{\text{Sum of results of corresponding KPI's in percentage}}{\text{Number of KPI Under Consideration}} \quad (3),$$

where, p is the number of KPI associated with the j^{th} students' outcome, j = *a* to *k* are the ABET learning outcomes for BS Computer Science program, and *a* to *n* for ABET learning outcomes for BS Information technology program (as applicable). For example: the j^{th} SO is associated with the KPI number p, q, r then the calculated learning outcome. $S_j = (k_p + k_q + k_r)/3$.

4.4 MATHEMATICAL MODEL FOR THE CLOs

The course learning outcomes are clear and concise statements that provide the students

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expected and achievable skills by the end of the semester. The CLOs should be related to the topics in the course. Also, the CLOs are more detailed and specific than the program learning outcomes as it uniquely identifies the expected skills to be learned by a student. The important characteristics of the CLOs are

- Clear
- Measurable
- Using Verbs

This course learning outcomes are related the programming learning outcomes. Both CLOs and POs are mapped to each other to calculate the average score. Few example CLOs for the course *"Coding and Information Theory"* is provided below.

- Understand the definitions and basic properties of uniquely decodable, instantaneous, prefix and optimal codes, the entropy function, and error-correcting codes;
- Implement Huffman's algorithm for the construction of optimal codes;
- State and prove basic theorems, such as the McMillan and Kraft inequalities and Hamming's sphere-packing bound.
- State and apply deeper results, such as the Sardinas-Patterson Theorem and Shannon's Fundamental Theorem (for the binary symmetric channel);
- Construct some simple error-correcting codes, such as the binary Hamming codes, and understand their basic properties

This paper proposes the following mathematical model to be used to calculate the average score for each CLOs. Let us consider as follows,

C_i= Average of results of corresponding SLO's belonging to that ith CLO, where C_i denotes the ith course learning outcome. Let C_i course learning outcome is associated with the SLO, s, a, b and

$$C_i = \frac{S_a+S_b+S_i}{3} \quad (4)$$

The class have total N number of students. Class size may be divided into several categories based on the marks obtained question or group of questions corresponding to the KPI. In this paper, the class performance is divided into three categories progressive towards expectation [PE], meet expectation [ME] and exceed expectation [EE] based on the performance in the direct assessments midterm, class test, quizzes, and final examination. The following base table is used as guideline to calculate the average score of the outcome / KPIs.

5. RESULTS

Two courses are taken as samples to implement the developed mathematical models. The calculation of CLO's, KPI'S and SO's have been done based on the methodology described. In this approach, first, calculate the KPI's then calculate the CLO's with have a correspondence with the respective KPI's and finally the SO's will be calculated by taking the average of the corresponding CLO's.

Table 2: Marks scored by the students in each KPIs

Assessment Tools→	Mid Exam		Final Exam	Assignment 1		Assignment 2	Exercises	Final Exam
PLOs→	PLO(b)			PLO(d)			PLO(i)	
KPIs→	KPI-b2	KPI-b3	KPI-b4	KPI-d1	KPI-d2	KPI-d3	KPI-i1	KPI-i2
Max Marks→	11	5	23	2.5	2.5	5	10	12
Marks Scored→	11	5	23	2.5	2.5	5	10	12
	11	5	23	2.5	2.5	5	10	12
	11	5	17	2.5	2.5	5	8	9
	11	5	18	2.5	2.5	5	9	4
	11	5	19	2	2	4	8	7
	11	5	20	2.5	2.5	5	8	5
	11	5	13	2	2	4	7	10
	11	5	11	2.5	2.5	4	7	9
	10	4	17	2.5	2.5	5	8	5
	5	4	12	2.5	2.5	5	8	6
	3	4	3	2.5	2.5	5	7	2
	11	4	18	2.5	2.5	5	8	9
	1	4	8	2.5	2.5	5	8	6
	10	5	20	2	2	3	6	10
	11	5	23	2.5	2.5	5	9	6
	6	5	11	2	2	3	4	9

5.1 CASE 1

Course Name: Coding and Information Theory

Table 2 presents the marks scored by 15 students in each KPIs for the course *"Coding and Information Theory"*. The PLOs *b, d, i* of the ABET student outcomes are mapped to this course. The PLOs and KPIs associated with detailed in Table 3.

Table 3: PLOs and KPIs

PLOs	KPIs Considered
An ability to analyse a problem and identify and define the computing requirements appropriate to its solution. (b)	Ability to analyze and solve the problem
	Ability to develop prototype, test cases, evaluation and validation tools
	Ability to specify the software tools needed for a given problem/software development
An ability to function effectively on teams to accomplish a common goal. (d)	Ability to participate effectively as part of a team
	Ability to fulfill team roles assigned
	Ability to accomplish the team goals.
An ability to use current techniques, skills, and tools necessary for computing practices. (i)	Ability to apply knowledge of simulation tools, analysis and software's used
	Ability to choose modern tools, latest software, emulation, simulation tools necessary for computing practice

Table 4: Number of Students Attainment Levels in KPIs

Attainment Levels \ KPIs	KPI-b2	KPI-b3	KPI-d1	KPI-d2	KPI-d3	KPI-i1	KPI-b4	KPI-i2
EE	11	15	15	15	13	8	5	3
ME	0	0	0	0	0	5	4	4
PE	4	0	0	0	2	1	1	0
DNME	0	0	0	0	0	1	5	8
Average Score	81	100	100	100	91	78	67	61

Table 4 and Figure 2 presents the KPI values for each of the attainment levels. The mathematical model presented in section 4.1 is used to calculate the cell values (number of students). Table 5 presents the average values of the PLOs. The PLOs are provided in Table 3. The mathematical model presented in section 4.2 is used to calculate the average value for each of the outcome.

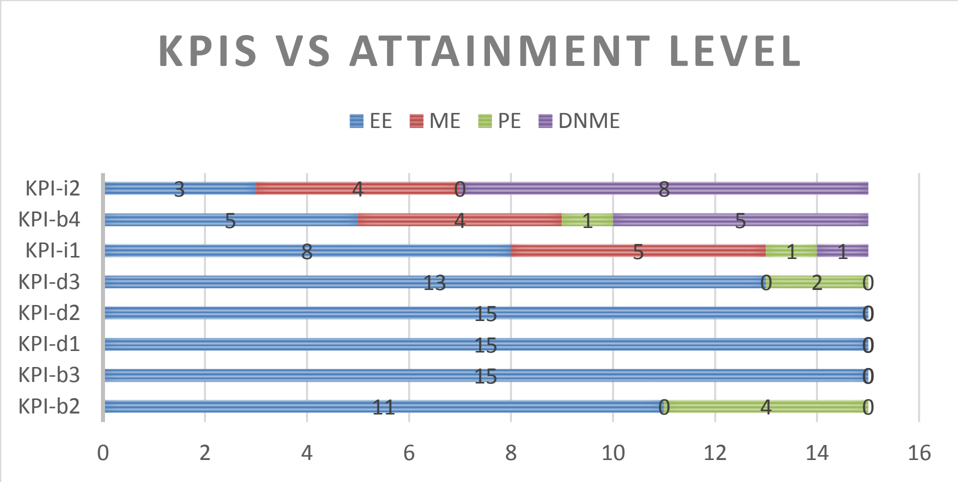

Figure 2: KPIs Vs Attainment Level

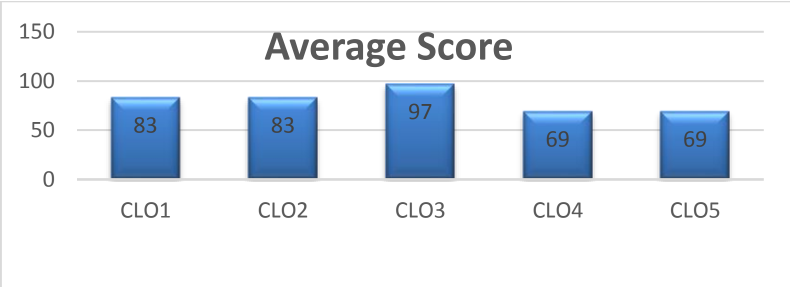

Figure 3: Average Score in CLOs

Table 7: Marks scored by the students in each KPIs

Assessment Tools→	Mid Exam	Exercise / Final Exam	Mid Exam/ Exercise	
PLOs→	PLO(a)		PLO(b)	
KPIs→	KPI-a1	KPI-a3	KPI-b1	KPI-b2
Max Marks→	22	30	19	29
Marks Scored by Students→	17	27	15	16
	15	19	16	10
	20	27	17	12
	15	24	15	17
	21	30	19	25
	17	20	16	7
	15	17	17	12
	13	27	14	15
	16	23	16	16
	19	21	14	18
	18	21	17	10
	17	25	14	24
	17	22	15	12
	20	27	18	21
	15	22	15	15
	20	24	14	16
	15	10	13	6
	17	24	17	18
	18	18	15	20
	16	23	15	17
	21	29	17	24
	15	23	14	13
	14	21	16	19
	15	20	15	10
	18	17	15	17
	15	25	16	14
	15	24	17	20
	15	24	15	20
	16	22	17	16
	17	24	18	17

Table 5: Average Score in PLOs

PLO	Average Score
b	83
d	97
i	69

Table 6: Average Score in CLOs

CLO	Average Score
CLO1	83
CLO2	83
CLO3	97
CLO4	69
CLO5	69

Table 6 and Figure 3 presents the average values of the CLOs. The mathematical model presented in section 4.3 is used to calculate the average value for each of the outcome.

5.2 CASE 2

Course Name: Calculus 2

Table 7 presents the marks scored by 30 students in each KPIs for the course *"Linear Algebra"*. The PLOs a,*b* of the ABET student outcomes are mapped to this course. The PLOs and KPIs associated with detailed in Table 8.

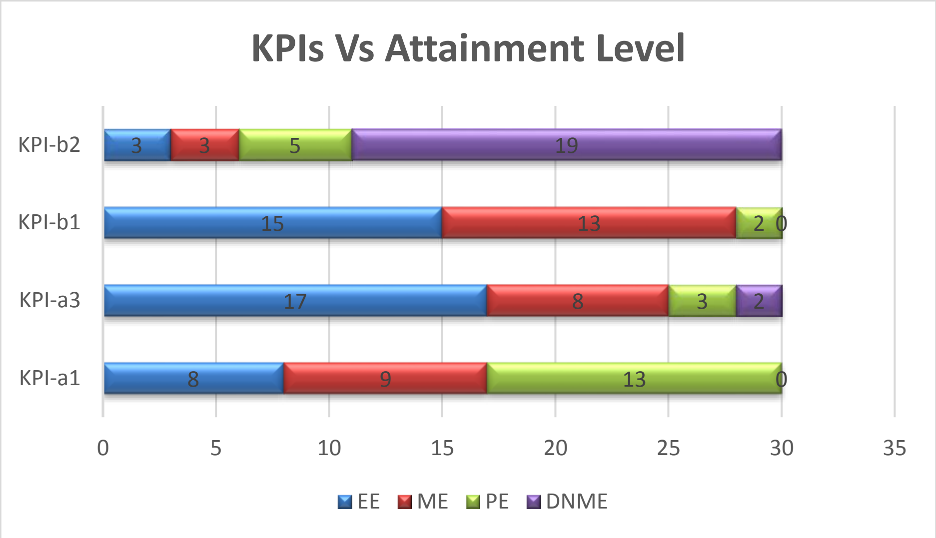

Figure 4: KPIs Vs Attainment Level

Table 8: PLOs and KPIs

PLOs	KPIs Considered
An ability to apply knowledge of computing and mathematics appropriate to the discipline. (a)	Ability to apply knowledge of mathematics (e.g., statistics, probability, discrete mathematics)
	Ability to use algorithmic knowledge to present a feasible algorithmic solution to a problem
An ability to analyse a problem, and identify and define the computing requirements appropriate to its solution. (b)	Ability to identify key points of the project. Ability to formulate an approach to solve.
	Ability to analyze and solve the problem

Table 9 and Figure 4 present the KPI values for each of the attainment levels. The mathematical model presented in section 4.1 is used to calculate the cell values (number of students). Table 10 presents the average values of the PLOs. The PLOs are provided in table 3. The mathematical model presented in section 4.2 is used to calculate the average value for each of the outcome.

Table 9: Number of Students Attainment Levels in KPIs

Attainment Levels \ KPIs	KPI-a1	KPI-a3	KPI-b1	KPI-b2
EE	8	17	15	3
ME	9	8	13	3
PE	13	3	2	5
DNME	0	2	0	19
Average Score	77	75	82	55

Table 10: Average Score in PLOs

PLO	Average Score
a	76
b	68

Table 11: Average Score in CLOs

CLO	Average Score
CLO1	72
CLO2	72
CLO3	68
CLO4	68

Table 12: PLO Scores for proposed and existing model for Calculus 2

PLO	Existing Approach	Proposed Approach
a	76	75
b	68	67

Table 13: PLO Scores for proposed and existing models for Coding and Information Theory

PLO	Existing Approach	Proposed Approach
b	83	75
d	97	93
i	69	68

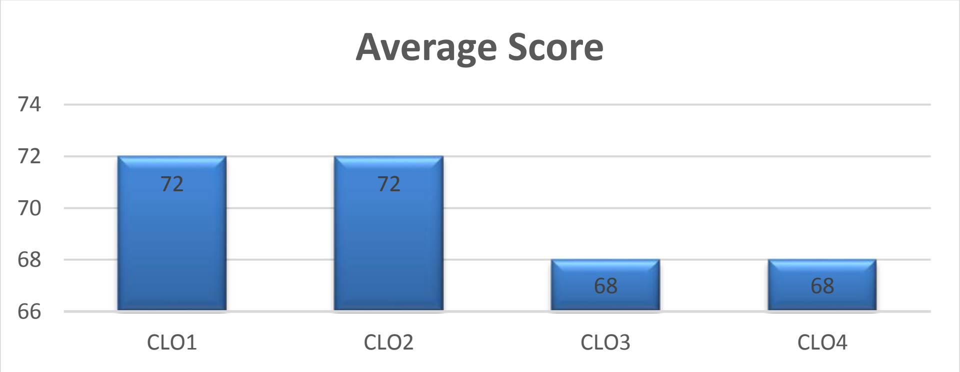

Figure 5: Average Score in CLOs

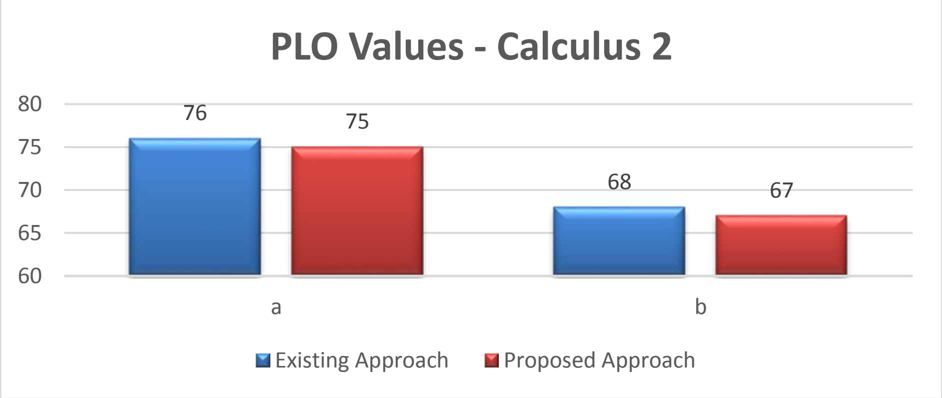

Figure 6: Average Score in PLOs - Calculus 2

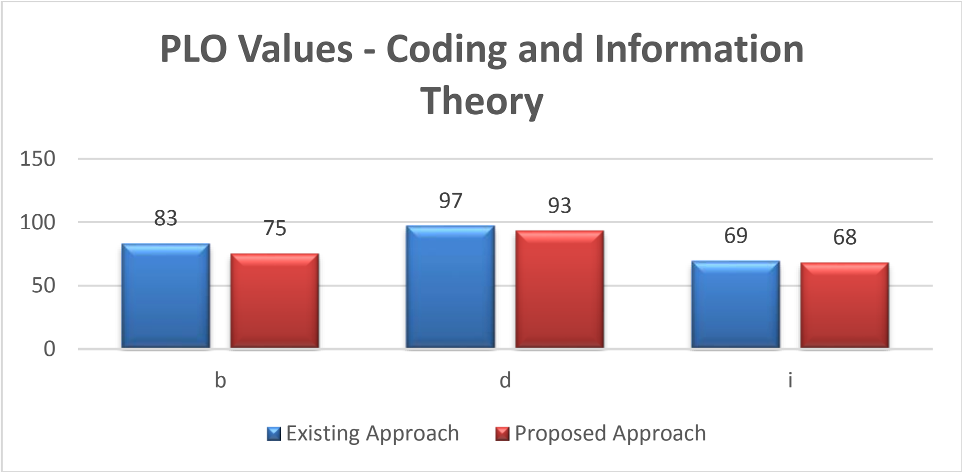

Figure 7: Average Score in PLOs – Coding and Information Theory

Table 11 and Figure 5 presents the average values of the CLOs. The mathematical model presented in section 4.3 is used to calculate the average value for each of the outcome.

It is noted from Figures 6 & 7, the proposed approach gives the values close to the existing approach. This clearly indicates that there is a high degree association between the proposed approach and the existing approach. The advantage of the proposed approach is the exit analysis of the courses in a micro level (KPIs and CLOs). Overall, the developed mathematical model is a standard approach, which can be used to calculate the average scores for KPIs, CLOs, and PLOs.

6. CONCLUSION

This paper presented mathematical models to evaluate the average scores of the program learning outcomes and course learning outcomes. The developed models are tested for two courses in the college of computer and information sciences of Majmaah University, Kingdom of Saudi Arabia. Using the developed mathematical models, the scores shows the attainment levels in each outcomes/KPIs. Based on the acceptance level in the Departments, efforts will be taken in the near future to develop a software system using this developed mathematical models. It is also concluding that the evaluation of course learning outcomes based on the KPI may help in the teaching-learning process, decision makers and at the end for the industry. The key performance indicator also helps for in prediction of results in the course so that the concern teacher can plan the teaching strategies as the students' performance in the KPI. This approach is useful to identify the skills of the students and achievement in the specific skill. The KPI has been measured based on the performance category of the students. The different performance categories have their different weights, the high weightage has been assigned for the students who have the good performance this is better measurement than by considering only the average of the performance of the students. Eventually, it will help in the accurate measurements of the students' outcome.

However, in future by applying the optimization techniques for choosing the weight may help in the selection of the weights of the different categories of the students.

7. ACKNOWLEDGMENT

The authors thank Deanship of Scientific Research at Majmaah University for supporting this work under Project Number No. 1440- 57.

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