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Conceive Design Implement Operate Approach for a Lab Module

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***Abstract*---**The Conceive-Design-Implement-Operate has been globally recognized as an enabler for engineering education reformation. With the CDIO process, the CDIO Standards and the CDIO Syllabus, many scholarly contributions have been made in curriculum reform and learning environments. Therefore, CDIO approach recognizes that the engineering education can be acquired from a variety of institutions and the educators in all parts of this spectrum can learn the CDIO practice elsewhere. Thus, the purpose of this study is to use the CDIO approach for an Engineering Mathematics Lab Module. For Concieve stage, three different pre-tests were conducted to identify the difficult course outcome in Engineering Mathematics for the students. A total of eight course outcomes are identified as the most difficult course outcomes in Engineering Mathematics subjects. In the design stage, an innovative lab module was developed based on the difficult course outcomes from the conceive stage. The lab module was designed in analytical and using Mathematica software. The Engineering Mathematics Lab Module was implement to Electrical Engineering department students. In the operation stage, the response from the students were obtained for the Engineering Mathematics Lab Module. Generally students' performance were improved in Engineering Mathematics using CDIO approach.

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***Keywords*---**conceive design implement operate (CDIO), engineering mathematics, lab module, innovative, course outcome.

Introduction

Curriculum reform in engineering education is very much on the agenda nationally and internationally. An immediate effect on this is the shortage of professional engineering skill [1]. Engineering skills directly contribute to the global economy, environment, security and health. Engineering science which supports all industries are able to maintain and promote the economic stability and development [2]. There are many factors that contribute to the curriculum change in higher engineering education such as to establish alternatives in traditional programme consists of disciplinary theoretical courses [3]. Thus the involvement of engineering education is necessity to increase the quality and to improve the results of education. This includes to increase the quality and to improve the results of education. This includes to increase attractiveness to prospective students, to lower the attrition and to improve the preparation for professional practice which contributes to sustainable development, innovation and job creation [4].

Integrated engineering activities analyzed a wide range of solutions of different problems during planning, design, manufacturing and application of technological processes [5]. The Conceive-Design-Implement-Operate (CDIO) concept developed in Massachusetts Institute of Technology (MIT) with the participation of leading universities from Sweeden is used by the world's leading universities and other universities for training specialists in integrated engineering activities [6].
The CDIO concept promotes the notion that "learning activities are crafted to support explicit pre-professional behavior" [7]. This need for change is supported by stakeholder feedback. The employers want proficient engineering students who can "hit the ground running". This means the engineering graduates should understand how to conceive, design, implement and operate the systems associated with their discipline [8].

Methodology

CDIO of conceive stage

At the conceive stage, preliminary test was conducted for each of the Vector Calculus, Linear and Differential Equation subject. The test was conducted at the end of the semester which is on week fourteen. The test questions were set up based on the course outcome, programme outcome and the Bloom Taxonomy level. The duration of each test is two hours. The preliminary test questions were validated by three experts. The Vector calculus preliminary test was conducted in the semester I of 2015/2016 session. A total of five subjective questions were designed for the test. A total of 42 students from the Department of Electrical, Electronic and Systems (JKEES), Universiti Kebangsaan Malaysia had participated in the test. As the first step, students marks were compiled in the *prn format. Then the marks were transferred to WINSTEPS. The analysis of WINSTEPS [9] was done against Rasch model. In this study, polytomous Rasch model with Likert scale [10] will be used to analyze the data.

Table I shows the summary of the Vector Calculus preliminary test. From the table, there are 3 course outcomes that are identified as difficult for the students. They are course outcome 1, course outcome 3 and course course outcome 4. A preliminary test for Linear Algebra was conducted in semester II session 2015/2016. A total of 79 students from JKEES participated in the test. There are five course outcomes for this subject and five subjective questions were prepared for this test. Table II shows the summary of Linear Algebra preliminary test. From the table, there are 2 difficult course outcomes for Linear Algebra subject. They are course outcome 2 and course outcome 5.

A preliminary test was conducted for Differential Equations subject in semester I session 2015/2016. A total of 100 JKEES students participated in this test. Six course outcomes are designed for this subject. This preliminary test consists of six questions. Table III shows the summary of Differential Equations preliminary test. From the table there are 2 difficult course outcomes for Differential Equations subject. They are course outcome 3 and course outcome 5. Table IV summarises the difficult course outcomes for the Vector Calculus, Linear Algebra and Differential Equations subject. Although the course outcome 2 from Differential Equations preliminary test is only moderate level of difficulty, but it is also taken as normally it needs 8 weeks of laboratorial sessions to conduct the Engineering Mathematics lab. The table also shows the description of the course outcome together with the Bloom Taxonomy level. These course outcomes will be taken to the next stage of CDIO, the design stage.

Table 1
Level of difficulty of vector calculus preliminary test

Question	*Course Outcome*	*Bloom Taxonomy Description*	*Difficulty Level of Question*
1	2	Application	Difficult
2(i)	3	Comprehension	Moderate
2(ii)	4	Analysis	Moderate
3	4	Analysis	Difficult
4(i)	5	Application	Easy
4(ii)	5	Evaluation	Difficult
4(iii)	5	Application	Very Difficult
5	6	Application	Easy

TABLE 2
LEVEL OF DIFFICULTY OF LINEAR ALGEBRA PRELIMINARY TEST

Quest ion	*Course Outcome*	*Bloom Taxonomy Description*	*Difficulty Level of Question*
1(i)	1	Knowledge	Easy
1(ii)	1	Evaluation	Moderate
1(iii)	1	Synthesis	Easy
2	2	Comprehension	Difficult
3(i)	3	Analysis	Moderate
3(ii)	3	Analysis	Easy
4(i)	4	Comprehension	Moderate
4(ii)	4	Application	Moderate
5	5	Application	Difficult

TABLE 3
LEVEL OF DIFFICULTY OF DIFFERENTIAL EQUATIONS PRELIMINARY TEST

Question	*Course Outcome*	*Bloom Taxonomy Description*	*Difficulty Level of Question*
1	1	Comprehension	Easy
2	2	Application	Moderate
3	2	Application	Moderate
4(i)	3	Comprehension	Easy
4(ii)	3	Analysis	Moderate
4(iii)	3	Application	Difficult
4(iv)	3	Analysis	Difficult
5	4	Application	Easy
6(i)	5	Analysis	Moderate
6(ii)	5	Comprehension	Difficult

TABLE 4
SUMMARY OF THE DIFFICULT COURSE OUTCOMES FOR ENGINEERING MATHEMATICS

Subject	*Course Outcome*	*Description of Course Outcome*	*Bloom Taxonomy Level*
Vector Calculus	2	Able to apply the basic concept of partial derivatives.	Application

Subject	*Course Outcome*	*Description of Course Outcome*	*Bloom Taxonomy Level*
Vector Calculus	2	Able to apply the basic concept of partial derivatives.	Application
Vector Calculus	4	Able to apply the concepts of line integral, double integral and triple integral in solving engineering problems.	Analysis
Vector Calculus	5	Able to apply Green's theorem, Stokes' theorem, Gauss' theorem in solving engineering problems.	Application/ Evaluation
Linear Algebra	2	Able to use concepts of vector space, linear independent in space dimension and matrix transformation.	Comprehension
Linear Algebra	5	Able to understand the concept of power series.	Application
Differential Equations	2	Able to solve first and second orders of differential equations.	Application
Differential Equations	3	Able to perform the step-by-step analysis to model the	Application /Analysis

Subject	*Course Outcome*	*Description of Course Outcome*	*Bloom Taxonomy Level*
Vector Calculus	2	Able to apply the basic concept of partial derivatives.	Application
		simple engineering problem using the second order non-homogeneous differential equations using an appropriate technique.	
Differential Equations	5	Able to use Fourier series to solve partial differential equations.	Comprehension

CDIO of design stage

All the difficult course outcomes from Table 4 are selected to design an Engineering Mathematics lab module. The difficult course outcomes which were identified from the preliminary test for Vector Calculus, Linear Algebra and Differential Equations are selected as the eight topics for the lab module. For each of the lab topics, questions were gathered to fulfill the course outcomes. Then, the question was keyed in into *Mathematica* software. *Mathematica* software was run and it gave the output for the question. Both the questions and the solutions for all the topics were given to three experts to verify the content and the solutions. If the experts are not satisfied, the questions need to be changed and the solution will be obtained using *Mathematica*. Once the experts are satisfied, the design part of the Engineering Mathematics lab module will then be complete.

Mathematica was selected to run a laboratory session because the function and structure of the language were easy to implement. The programming language is a highly structured functional programming and it is tailored to various theoretical and technical applications. *Mathematica* has helped students to understand difficult mathematics concepts in no time with the use of the built-in functionality. Representatives of mathematical concepts in the form of graphs and simulations also facilitate a holistic understanding of students.

CDIO of implement stage

For the implementation stage of CDIO, a pre-test was conducted on sixty JKEES students. This test was conducted in semester I 2016 / 2017. The students were in their third semester of the course. In that semester, the students were studying Differential Equations subject. Prior to that, the students studied Vector Calculus and Linear Algebra subjects. The Course Outcomes related to the pre-test is a mixture of Vector Calculus, Linear Algebra abd Differential Equations subjects. Six subjective questions were designed and the questions were grouped into easy and moderate questions. The duration of the pre-test is 2 hours. Table 5 shows the Course Outcome and the level of pre-test questions.

TABLE 5
COURSE OUTCOMES AND LEVEL OF PRE-TEST QUESTIONS

Question	*Course Outcome*	*Level*
1	Able to apply Green's theorem, Stokes' theorem, Gauss' theorem in solving engineering problems.	Moderate
2	Able to use concepts of vector space, linear independent in space dimension and matrix transformation.	
3	Able to understand the concept of power series.	Moderate
4	Able to apply the basic concept of partial derivatives.	Moderate
5	Able to solve first and second orders of differential equations.	Moderate
6	Able to apply the concepts of line integral, double integral and triple integral in solving engineering problems.	Easy

CDIO of operate stage

A pilot test was conducted in semester II 2016 / 2017. A total of 35 students from Electrical Engineering, Civil Engineering and Chemical Engineering department participated in the test. Exam questions were constructed based on Course Outcome and Programme Outcome. The questions were validated by three internal experts. The duration of the test was 2 hours and 6 subjective questions were prepared. The pilot test questions were from moderate and easy level. The profile of the students who took the pilot test as listed in Table VI. The composition of students are given in Table VII. Table VIII shows the Programme Outcome for the pilot test questions. There are a total of 12 Programme Outcomes for the Engineering Programme. Table IX illustrates the distribution of pilot test questions together with the marks.

TABLE 6
PROFILE OF STUDENTS

Department	*Number of Students*
Electrical Engineering	13
Chemical Engineering	12
Civil Engineering	10
Total	35

TABLE 7
STUDENTS' COMPOSITION

Gender	*Number of Students*	*Percentage*
Male	20	57
Female	15	43
Total	35	100

TABLE 8
PROGRAMME OUTCOME FOR PILOT TEST

Programme Outcome	*Description*
1	Engineering knowledge
2	Problem analysis
3	Design / development of solutions
4	Investigation

Programme Outcome	*Description*
1	Engineering knowledge
5	Modern tool usage
6	The engineer and society
7	Environment and sustainability
8	Ethics
9	Communication
10	Individual and team work
11	Lifelong learning
12	Project management and finance

The details entry of each pre-final questions is given in Table X. The table shows the questions, Course Outcome, Programme Outcome and the level of difficulty of each question. All the marks are entered in the Excel *prn format. The file was transferred using Bond & Fox Steps [8], which is a customized WINSTEPS. The WINSTEPS provides details description on Summary Statistics for Item and Person-Item Distribution Map. Summary statistics for item gives detail description of the items (questions) and the persons (students). Fig. 1 shows the summary statistics for items. From Fig. 1, the summary statistics reveals an average spread of item difficulty with item reliability of 0.69. Higher value of item reliability increases the possibility of the item having similar attempt when given similar test [9]. This means among pilot test questions there are some which is difficult and some which is easy. The spread of the items are from minimum logits of -0.82 to maximum logit at 1.08. Item mean (measure) is 0. The item separation indicates number of the groups the question can be divided. The summary statistics shows that the item separation is 1.49. This means the pilot test questions can be divided into 2 group.

Fig. 2 shows items statistics for the pilot test. In identifying the misfit item in the pilot test, the procedure starts with examine the item polarity, Outfit MNSQ and Outfit *z*-std. The Point Measure Correlation need to be within the range of $0.4 < x < 0.8$. From Figure 2, item 3, item 4, item 5 and item 6 are out of the Point Measure Correlation range. Next, the value of Outfit MNSQ is examined. The range of Outfit MNSQ is $0.5 < MNSQ < 1.5$. From Fig. 2, item 3, item 4, item 5 and item 6 is out of the range. The range of Outfit z-std is $-2 < z < 2$. Item 6 is out of range of Outfit z-std. Since item 6 is out of range of Point Measure Correlation, Outfit MNSQ and Outfit *z*-std therefore item 6 is misfit for the pilot test. This means the students were not able to answer this question. Item 6 will not be withdraw from the pilot test. This question is the most difficult question for the students.

TABLE 9
PILOT TEST QUESTIONS

Question	*Description*	*Marks*
1	Use the Green theorem to evaluate $\oint_C xydx + x^2y^3dy$; where C is a triangle with vertices (0,0), (1,0), (1,2).	6
2	Compute the projection of (1,2,3) onto (-2,3,-1) using inner product $<\mathbf{a,b}>= 2a_1b_1 + 3a_2b_2 + 4a_3b_3$. .	6
3	Obtain power series representation of x^5 in power of $x-2$.	6
4	The plane tangent to the surface defined by $z = f(x, y)$ at the point is (x_0, y_0, z_0). Determine the equation of the plane tangent to the paraboloid $z = 10 - x^2 - 2y^2$ at the point where $x = 1$ and $y = 2$. Sketch the plane tangent and the paraboloid.	9
5	Solve the equation $\frac{dy}{dx} = x + y$ with initial condition $y(0) = 2$. Then plot the solution.	9
6	Find the volume of the solid that lies under the paraboloid $z = x^2 + y^2$, above the $xy-$ and inside the cylinder $(x-1)^2 + y^2 = 1$.	12

TABLE 10
ENTRY NUMBER FOR PILOT TEST QUESTIONS

Question	*Course Outcome*	*Programme Outcome*	*Difficulty Level*
1	1	2	Moderate
2	2	1	Easy
3	3	2	Moderate
4	4	1	Moderate
5	5	1	Moderate
6	6	1	Moderate

SUMMARY OF 5 MEASURED (NON-EXTREME) Item

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	53.2	35.0	.00	.32	.80	-.1	.94	.0
S.D.	17.2	.0	.71	.23	.23	.6	.56	.8
MAX.	77.0	35.0	1.08	.75	1.16	.8	1.97	1.3
MIN.	36.0	35.0	-.82	.14	.53	-1.1	.44	-1.3

REAL RMSE	.39	TRUE SD	.59	SEPARATION	1.49	Item RELIABILITY	.69
MODEL RMSE	.39	TRUE SD	.59	SEPARATION	1.50	Item RELIABILITY	.69
S.E. OF Item MEAN = .35							

Fig. 1 Summary statistics for item.

Fig. 3 shows unexplained raw variance by measure is 45%. This value fulfill the minimum requirement measurement 40%. Therefore, the instrument is within the acceptable dimensionality and it showed enough reliability in measuring the students' problem-solving skills in pilot test questions. This value explains that the questions of the pilot test are unidimensional. The unexplained variance of the 1st contrast is 22.2%. This value is out of the range 5% to 15%. Thus the item correlation value is examined to check whether the items are dependent on each other. Fig. 4 shows the item correlation. Item correlation above 0.7 shows the item is dependent on each other. From Fig. 4, there is no correlation more than 0.7. Thus no item is aborted. Fig. 5 shows the Person Item Distribution Map where Rasch model provides the location of all the person on the vertical logit ruler, indicated by the dashed vertical line. The higher the person located on the map, it indicate the most competent the student is. On the contrast, the item is like the hurdle to the students. The higher the item is on the ruler, the more difficult the question is.

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PT-MEASURE CORR.	PT-MEASURE EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
6	35	35	1.81	1.49	MAXIMUM MEASURE				.00	.00	100.0	100.0	6
5	36	35	1.08	.75	.53	.1	.49	.0	.16	.12	95.2	97.0	5
4	39	35	.38	.34	.59	-.2	.44	-.4	.30	.22	81.0	87.0	4
3	43	35	.07	.24	.91	.0	1.97	1.3	.16	.30	57.1	63.7	3
1	71	35	-.71	.14	1.16	.8	1.06	.4	.61	.61	.0	14.1	1
2	77	35	-.82	.14	.78	-1.1	.73	-1.3	.71	.66	4.8	11.4	2
MEAN	50.2	35.0	.30	.51	.80	-.1	.94	.0			47.6	54.6	
S.D.	17.1	.0	.93	.48	.23	.6	.56	.8			38.9	35.9	

Fig 2. Item statistics

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Table of STANDARDIZED RESIDUAL variance (in Eigenvalue units)
                                              -- Empirical --    Modeled
Total raw variance in observations     =        9.1 100.0%         100.0%
  Raw variance explained by measures   =        4.1  45.0%          40.8%
    Raw variance explained by persons  =         .3   2.8%           2.5%
    Raw Variance explained by items    =        3.8  42.2%          38.2%
  Raw unexplained variance (total)     =        5.0  55.0% 100.0%   59.2%
    Unexplned variance in 1st contrast =        2.0  22.2%  40.5%
    Unexplned variance in 2nd contrast =        1.4  15.1%  27.5%
    Unexplned variance in 3rd contrast =        1.0  10.8%  19.7%
    Unexplned variance in 4th contrast =         .6   6.6%  12.0%
    Unexplned variance in 5th contrast =         .0    .1%    .3%
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Fig. 3. Item dimensionality

The discussion aims at the performance of the item of all the 6 questions spread on the logit scale. On the right hand side of the dashed line, the questions are aligned from easy to difficult, starting from the bottom. The distribution of students is on the left side of the verticle dashed line is increasing the order of ability. Letter 'M' describes the students. Item mean, 'S' is one standard deviation distance from the mean and 'T' marks two standard deviation distances from the mean. CH01 means a student who took the pilot test from chemical engineering department, EE11 means a student from the electrical engineering department and CV03 means a student from civil engineering department.

From Figure 5, the questions can be divided into 2 groups. In order to establish the cut-off point of the 2 groups on the logit ruler, it starts from the mean item 0.00 logit. At mean 0.00, Rasch model established a virtual zero of the logit ruler [10]. At this point, given a task, a person has 50:50 chance of success in performing the task, before he decides based on his experience that he may or may not be able to complete the task. Questions above the mean line are defined in the 'difficult caegory'. From a total of 6 questions, 4 questions fall into the 'difficult' category. The questions in the 'difficult' category are question 3, question 4, question 5 and question 6. On the other hand, questions below the mean line are easy for the students to answer during the pilot test. Question 1 and question 2 are the ones deemed easy to solve. In terms of the Course Outcomes, Course Outcome 1 and Course Outcome 2 fall in the easy category. Students find easy to apply Green's theorem, Stokes' theorem and Gauss' theorem in engineering applications. Students also find easy to use the concept of vector space, linear indepenedent in the space dimensions and matrix transformation.
Course Outcome 3, 4, 5 and 6 very difficult for the students. Students find difficult to understand the power series and partial derivatives. Students also face difficulties in applying the concept of line integral, double integral and triple integral in engineering applications. Solving first and second order of differential equations are also difficult for the engineering students. Table XI summarises the results of Person-Item distribution map.

CORREL-ATION	ENTRY NUMBER	I	ENTRY NUMBER	I
.26	2	2	5	5
.15	2	2	4	4
.09	3	3	4	4
-.69	1	1	2	2
-.52	1	1	4	4
-.35	2	2	3	3
-.32	1	1	3	3
-.26	1	1	5	5
-.10	4	4	5	5
-.08	3	3	5	5

Fig. 4. Item correlation

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Fig 5. Person-Item Distribution Map

TABLE 11
SUMMARY OF THE PERSON-ITEM DISTRIBUTION MAP

Question	*Subject*	*Course Outcome*	*Difficulty Level of Question*	*Difficulty Level from PIDM*
1	Vector Calculus	Able to apply the basic concept of partial derivatives.	Moderate	Easy
2	Vector Calculus	Able to apply the concepts of line integral, double integral and triple integral in solving engineering problems.	Easy	Easy
3	Vector Calculus	Able to apply Green's theorem, Stokes' theorem, Gauss' theorem in solving engineering problems.	Moderate	Difficult
4	Linear Algebra	Able to use concepts of vector space, linear independent in space dimension and matrix transformation.	Moderate	Difficult
5	Linear Algebra	Able to understand the concept of power series.	Moderate	Difficult
6	Differential Equiations	Able to solve first and second orders of differential equations.	Moderate	Difficult

Conclusion

The Conceive-Design-Implement-Operate (CDIO) was used on an engineering Mathematics lab module. At the conceive stage, three preliminary test were conducted for the Engineering Mathematics subjects. This was followed by designing the Engineering Mathematics lab module. In the next phase, the implementation of the Engineering Mathematics lab module begins to the sixty JKEES students. On the operational part of the study, it was observe that the module showed a positive results among engineering students. Thus CDIO method is a well organize approach for the development and assessment of the Engineering Mathematics lab module.

This study is a pioneer study before implementing teaching via lab sessions for Engineering Mathematics subject. This study analyzed a pilot study which consist of 35 students from engineering background. The six Course Outcome consists from different subjects of Engineering Mathematics which are Vector Calculus, Linear Algebra and Ordinary Differential Equations. Thus six subjective questions were designed and validated by internal experts. The test results were analyzed against Rasch model. The summary statistics of items shows that the pilot test questions can be divided into two groups. The person-item-distribution map further elaborate on the questions which belongs to the easy and difficult category. Partial derivatives, line integral, double integral and triple integral are among the easy topics in Engineering Mathematics. Green's theorem, Stokes' theorem, Gauss' theorem, concepts of vector space, power series, first and second order of differential equations are among difficult topics in Engineering Mathematics.

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