Programme Outcome Attributes related to Complex Engineering Problem Capability: Perceptions of Engineering Students in Malaysia

Che Maznah Mat Isa[1*], Nik 'Irfan Aiman Mohammad[2,] Nor Hayati Saad[3] & Christopher Nigel Preece[4]

[1,2,3] School of Civil Engineering, College of Engineering, Universiti Teknologi MARA,
40450 Shah Alam, Selangor, Malaysia
[*]chema982@uitm.edu.my
nirfanaiman@gmail.com
norhayatisaad@uitm.edu.my
[4]College of Engineering and Computer Science
Abu Dhabi University, Abu Dhabi, United Arab Emirates
christopher.preece@adu.ac.ae
[*]Corresponding Author

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Abstract: Programme outcomes (POs) are the attributes that reflect the student skills expected to be acquired upon graduation. The Engineering Accreditation Council (EAC) under Board of Engineers Malaysia requires 12 POs with complex engineering problems (CEP) and knowledge profiles to be incorporated in engineering programmes. Despite considerable research on outcome-based education (OBE), the OBE implementation with regards to the PO attributes and domains incorporating CEP characteristics are still questionable and vaguely implemented by the programmes. This paper presents two PO attributes related to problem solving and development/design for solution based on the perceptions of 301 engineering students in Malaysia. This paper aims to determine the student's level of understanding on the PO learning domain and to analyze significant factors contributing to their PO attainment. A quantitative method using a questionnaire survey was adopted targeting a random probability sampling of respondents. Descriptive (percentage frequency, relative importance index) and statistical analyses (reliability, normality, correlation) were used to analyze the data. The findings show that the students perceived both POs as cognitive domains and they believed that lecturer's roles in facilitating students on the subject matter has contributed significantly to their PO attainment. This study is limited to an engineering programme from one institution of higher learning (IHL) in Malaysia. However, the findings provide important insights on the students' level of understanding of PO attributes and the OBE practices on CEP in the programme. This study can be extended to other IHLs to gauge the students' understanding related to other PO attributes stipulated by the EAC.

Keywords: Programme Outcomes, Cognitive Domain, Problem Analysis, Design of The Solution, Engineering

1. Introduction

Programme outcomes (POs) are the graduate attributes that reflect on the knowledge and skills that are expected to be acquired by the students upon graduation. The POs attained by the students were evaluated through an accreditation process based on the level of attainment of graduate attributes supported by evidence on factual accuracies and direct measurement provided by the programmes. In Malaysia, the Board of Engineers Malaysia (BEM) manages the accreditation process through the

Engineering Accreditation Council (EAC) to evaluate engineering programmes (Hamzah & Mat Isa, 2017). Most evaluation of engineering projects is based on the POs assigned to the course (Ab Wahid et al., 2020). Universities that offer engineering courses in Malaysia need to fulfil the minimum requirements set by the BEM to ensure that the programmes are being recognized, hence the graduates will be able to carry out relevant engineering practices during their career life. In Malaysia, since 2004, OBE is the prime criterion for engineering accreditation required by the Engineering Accreditation Council (EAC) to be qualified as a full member of the Washington Accord (WA). The EAC Standard 2020 has prescribed 12 programme outcomes or graduate attributes with complex engineering problems (CEP), complex engineering activities (CEA) and knowledge profiles (WK) to be incorporated in all engineering programmes. A recent study revealed that the implementation on OBE with regards to CEP and CEA is still in the infancy stage especially on the assessment tools used to measure these characteristics as prescribed in the EAC Standard 2020 (Mat Isa et al., 2021). Despite extensive studies on OBE, the implementation of OBE with regards to the PO attributes and domains together with the CEP, CEA and WK characteristics are still questionable and vaguely evident towards effective continual quality improvement (CQI) of the programme. Most of the engineering programmes adopt the OBE framework based on Bloom's Taxonomy (1956) in their programmes which is aimed to make students mindful of what they are realizing, subsequently endeavouring to accomplish increasingly advanced levels of learning with six subjective learning classifications (Rahman & Manaf, 2017). Bloom (1956) introduced the concepts for educational learning having three domains to reflect cognitive (knowledge-based domain), effective (attitude-based domain) and psychomotor (skills-based domain) skills. As future engineers, the students need to acquire the skills related to the cognitive domain which is seen as one of the important skills required in solving and finding the solutions for various complex problems. The cognitive domain is the processes that thinkers encounter and work with the knowledge that need to remember, understand, apply, evaluate and create (Waguespack & Babb, 2019). This study was conducted to determine the understanding of PO attainment and factors contributing to the attainment in engineering programmes from the students' perspectives.

2. Literature Review

Currently, Malaysia is one of the members of the Washington Accord (WA) which recognizes the accreditation of engineering programme qualifications among its country members. The outcome-based education (OBE) framework can be actualized deliberately in tertiary training programs (Khusaini, Jaffar, & Yusoff, 2013) in order to improve the quality of engineering education at the course and programme levels and also the achievement after graduation. Another important element in OBE is the teaching, learning and assessment (TLA) process that needs to be carried out effectively towards the PO development and attainment. This is to guarantee that engineering graduates created by the Malaysian universities would be recognized by the Washington Accord members like the United States, the United Kingdom, Australia and South Africa (International Engineering Alliance, 2011).

In addition, there are three (3) important domains associated with the POs as the expected outcomes to be achieved by the students upon graduation. These are the cognitive domain (C), affective domain (A) and psychomotor domain (P). Table 1 shows the 12 POs (categorized under three domains) adopted by the Civil Engineering school in UiTM Shah Alam according to the Washington Accord requirements. In this programme, the final year project (FYP I and FYP II) and the integrated design project (IDP) are the examples of the culminating courses that are normally used to measure the level of attainment of PO2 and PO3. Both POs need to be assessed directly and explicitly by the engineering programmes. The cognitive domain is commonly associated with problem analysis and design development solutions in the FYP and IDP courses where the direct assessment methods used require the students to demonstrate their learning and produce work in which their skills fit the programme level expectations which can be assessed by the evaluators (Hamzah & Mat Isa, 2017).

Table 1. Programme Outcomes for EC220 (School of Civil Engineering) (EAC Standard, 2020)

Program Outcome	Washington Accord (WA) Graduate Attributes incorporating knowledge Profile (WK), Complex Engineering Problems (WP) and Complex Engineering Problem (EA)
PO1 (C)	Engineering Knowledge: Apply knowledge of mathematical, natural science, engineering specialization to the solution of a **complex engineering problem**. (WK1-WK4)
PO2 (C)	Problem analysis: Identity, research, literature and analyze **complex civil engineering problems** reaching substantial conclusions using the first principle of mathematics, natural sciences and engineering sciences. (WK1-WK4)
PO3 (C)	Design/development of solutions: Design solutions for **complex engineering problems** and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal and environmental considerations. (WK5)
PO4 (P)	Investigation: Conduct investigation of complex engineering problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data and synthesis of the information to provide valid conclusions.
PO5 (C)	Modern Tool Usage: Create, select and apply appropriate techniques, resources and modern engineering and IT tools, including prediction and modeling to complex civil engineering problems with an understanding of the limitations. (WK6)
PO6 (C)	The Engineer and Society: Apply to reason informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems. (WK7)
PO7 (C)	Environment and Sustainability: Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental contexts. (WK7)
PO8 (A)	Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice. (WK7)
PO9 (A)	Individual and Teamwork: Function effectively as an individual and as a member or leader in diverse teams and multidisciplinary settings.
PO10 (A)	Communication: Communicate effectively on complex engineering activities with the engineering community and with the society at large, such as being able to comprehend and write effective reports and design documentation, make an effective presentation, and give and receive clear instructions. (EA)
PO11 (C)	Project Management and Finance: Demonstrate knowledge and understanding of engineering management principles and economic decision making and apply these to one's work, as a member and leader in a team, to manage projects and in
PO12	Lifelong Learning: Preparation for and depth of continuing learning

In FYP and IDP courses, the evaluations are commonly carried out by both internal and external panels to determine whether students have met the expectations of the course. In addition, the feedback provided to the students must be clearly expressed, readily observed, with fully revealed measurement and shown without vagueness, implication or ambiguity (Hamzah & Mat Isa, 2017). The culminating model is one of the effective methods to measure these programme outcomes upon graduation. The advantages of this method are they are controllable, voluntary but require a significant allocation of cognitive sources. The activities conducted during FYP and IDP indirectly will prepare the students to work in the real industry practices. It requires the students to think critically and creatively to find out the solutions for the given problem within a certain project duration. So, by using these courses as the indicators for the students' attainment level, the PO2 and PO3 can be measured effectively by using the direct and explicit attainment assessment such as project-based and examination (if relevant).

2.1 Problem Analysis (PO2)

Complex problem solving is challenging and a high-level cognitive process for everyone (Hagemann & Kluge, 2017). Complex problem solving "takes place for decreasing the boundary between a given start state and an expecting objective state with the assistance of cognitive activities and behaviour". Meanwhile (Dostál, 2015) stated that the problem is an intuitive connection between a subject and its environment, which relates the inner problem that is solved by the subject by looking at its moves from an initial condition to the final condition which is known as aim. The problem also can occur when someone has the aim, but he/she does not know how to get it. A meta-analysis combines the findings from existing studies and empirical evidence to examine the results from individual studies for the reason of integrating the findings of the PO attainment (Yusoff et al, 2014). Meta-analysis is a quantitative accumulation and analysis of the effect of sizes and others during studies and this method is able to analyse the literature using statistical procedures and econometric techniques that enable valid interferences to be drawn and help to validate the key relationship.

2.2 Design/Development of Solutions (PO3)

Engineering design is inherently complex and ill-defined with unknown constraints and criteria. Determining the characteristics and boundaries of the problem space is a crucial part of the design (Watkins, Spencer, & Hammer, 2014). The process to develop solutions does not only require the information about the problem, but also the solution and ideas to refine the initial problem scoping which occurs both at the start of the design process when the designer does not have a specific solution with them and also when they already redefine the problem as they develop the solutions (Watkins et al., 2014). Engineering design also often has been characterized as complicated and ill-defined which relates to traditional textbook end-of-chapter problems. For reasons in figuring out how to design, Jonassen (2011) has stated that the design problems can be represented by a series of decisions. Those design decisions depend on different constraints and limitation operation in the plan space. Toward the start of the design procedure, practical details and initial constraints are determined by some sort of needs for the analysis process. Designers firstly define the problem by making decisions. The solution to each decision depends on the kind of the decision it is, additional constraints that have been introduced into the problem, and whatever beliefs or assumptions are held by the designer.

3. Methodology

3.1 Research Design

This study adopts a quantitative method using a questionnaire survey converted into a Google Form as the research instrument. The survey was distributed via the media social platform such as WhatsApp and using the QR code to increase the response rate among the targeted respondents.

3.2 Sampling Design and Target Respondents

A probability sampling random method was used based on a sampling frame obtained from four (4) engineering schools in UiTM Shah Alam. Using Krejcie and Morgan (1970) table, the target respondents is n=384 students from overall population, N=1850 students in semester 7 and 8 (see Table 2). These students were currently taking the culminating courses namely, Integrated Design Project and Final Year Project.

Table 2. The Number of Final Year Engineering Students

School	Number of Final Years Students		
	Semester 7	Semester 8	Total
Civil Engineering	417	58	475
Mechanical Engineering	391	87	478
Electrical Engineering	211	391	602
Chemical Engineering	242	53	295
Total	1261	589	1850

3.3 Research Instrument

The items in the questionnaire survey were designed to address the research objectives based on the previous studies. The developed questionnaires consist of five (5) main sections. Section A enquires information on the respondents' background, Section B seeks the student's understanding on the learning domains of the engineering programmes, Section C asks on the student's current POs attainment and Section D focuses on the factors influencing students' POs. The measurement is based on a 5-Point Likert rating, where respondents need to evaluate the statement given based on the scale ranging from 1 to 5: (1) Strongly Disagree (2) Disagree (3) Moderately Agree (4) Agree (5) Strongly Agree.

3.4 Data Analysis

The descriptive (percentage frequency distribution) analysis and statistical (reliability and normality) analysis were used to analyse the quantitative data obtained from the well-structured questionnaires tested for its validity and reliability which was then used to determine the level of PO attainment of the students in this study.

3.5 Reliability and Normality Tests

To ensure the validity of the data collected, a reliability analysis with Cronbach's alpha value was calculated where the value that greater than 0.7 was considered as reliable and stable (Nunally, 1978). In addition, a normality test with the output given was in the form of numerical and graphical where the outputs were analyzed to determine the normality of data distribution. As the test was performed, the values obtained from the normality table provide the value of skewness and kurtosis where the data were considered normal if the values obtained were within the allowable range.

3.6 Relative Importance Index (RII)

The Relative Importance Index was used to determine the ranking of the items presented in the section with a 5-point Likert scale used as a measurement. The formula that had been used to calculate RII for a 5-point Likert scale as shown in Fig. 1:

$$\textbf{Relative Importance Index} = \frac{\sum w}{AN} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5N}$$

Fig.1. Formula to Calculate RII

Where: w is the weighting by the students for each of the items such as (1< w <5) and N is the total number of respondents. RII value (< 1) obtained was used to rank the items accordingly to show their level of priorities. By sorting the items according to their ranking, the most important criteria based on the respondents' feedback can be determined for further analysis.

3.7 Correlation Analysis

Correlation analysis was conducted to measure the strength and direction of the variability measured between two different variables based on the Pearson product-moment correlation. The data obtained from the survey was analyzed using intra-correlation to show the relationship between the factors influencing the PO attainment. Cohen (1988) indicated three levels of Pearson coefficient, which were between 0.1 – 0.29 (Small value – poor correlation), between 0.3 – 0.49 (medium value – medium relationship) and between 0.5-1.0 (large value – strong relationship).

4. Results and Discussion

This section presents the results analysis and discussion on findings obtained based on both descriptive and statistical analysis.

4.1 Reliability and Normality Test

The Cronbach's Alpha for the variables obtained through three main sections of the questionnaire on Section C (Programme Outcomes Attainment) and Section D (Factors Influencing Students' Attainment of Programme Outcomes) with 28 items, are 0.765 and 0.871, respectively. and The Cronbach's Alpha values for both sections are greater than 0.7 indicates that the instrument used was reliable (Nunnally, 1978). The Skewness and Kurtosis statistics tests used to test for normality using BIM SPSS software produced the data obtained near to zero indicated that the data were normally distributed (see Table 3).

Table 3. Skewness and Kurtosis value

Section	Skewness		Kurtosis	
	Statistic	Std. Error	Statistic	Std. Error
Section C	-0.082	0.140	0.673	0.280
Section D	0.182	0.140	0.565	0.280
Section E	-0.372	0.140	0.079	0.280

4.2 Respondent's Profile

Table 4 shows that out of 384 targeted respondents, 301 students answered the on-line survey giving a response rate of 78.4%. The profiles of respondents show that about 60.8% were male. Most of them were in semester 7 (76.1%) and others 23.9% in semester 8. Meanwhile, 54.8% of them were from diploma and 45.2% from the matriculation. For the degree enrolment year, most of them (44.5%) entered the degree in the year 2016. About 25% of them were from the Mechanical Engineering, 25% from the Civil Engineering, 35% from Electrical Engineering and 15% from Chemical Engineering. The profile showed that 46.5% of the respondents obtained CGPA between 3.00 to 3.49, 35.2% with CGPA between 2.00 to 2.99 and only 17.9% with CGPA between 3.50 to 4.00.

Table 4. Respondent's Profile

Item	**Frequency**	**Percentage**
Target Respondent (384)		
Responses	301	78.4%
Male	183	60.8%
Female	118	39.2%
Semester 8	229	76.1%
Semester 7	72	23.9%
Matriculation/Foundation	165	54.8%
Diploma	136	45.2%
School		
School of Civil Engineering	77	25.6%
School of Mechanical Engineering	78	25.9%
School of Electrical Engineering	101	33.6%
School of Chemical Engineering	45	15.0%
Total	301	100.0%
Respondents' Current CGPA		
Between 2.00 – 2.99	140	35.2%
Between 3.00 – 3.49	106	46.5%
Between 3.5 – 4.00	54	17.9%
Total	301	100.0%

4.3 Respondents' Opinion on the Learning Domain for PO2 and PO3

There were two (2) items placed in Section B that require the students' opinion on PO2 (Problem Analysis) and PO3 (Design/Development of Solutions) learning domain, respectively. Fig. 2 shows the percentage frequency distribution among the respondents. Almost 60% of the respondents opined that the PO2 domain belongs to the cognitive domain as it requires them to solve complex, challenging and demanding problems at high-level cognitive level (Hagemann & Kluge, 2017). Fig. 3 shows that 31% of the respondents perceived PO3 as a cognitive domain while 42% and 25% chose affective and psychomotor domains, respectively. This is associated with the cognitive and affective skills in design and development of solutions to solve the identified problems.

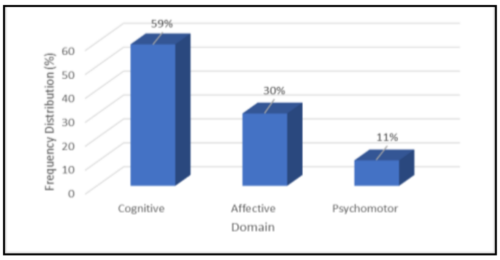

Fig. 2 Percentage Frequency Distribution of Respondents' Opinion related to PO2 Domain

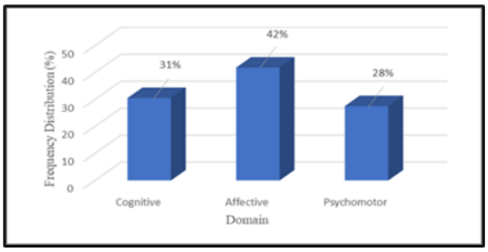

Fig. 3 Percentage Frequency Distribution of PO3- Design/Development of Solution

4.4 Respondents' Feedback on Actual PO2 and PO3 Attainment and the Importance of PO2 and PO2 Graduate Attributes

The four (4) items placed in Section C required the students' feedback on the actual PO attainment and the importance of both POs. Fig. 4 shows that only 17% of the respondents revealed that they obtain score more than 80% marks, while almost half (48%) scored between 60% to 79%. Around 26% scored between 50% to 59% and the rest (9%) of the respondents reported that their PO2 attainment was less than 50%. Validation of this PO2 attainment was done by comparing the actual marks form the OBE system, which showed that the average PO2 score was around 64% which aligned to the majority of the students' achievement. A study by Idrus et al. (2010) indicated that engineering students rated problem solving skills as the most important skill next to communication and leadership skills. Fig. 5 shows that about 73% (scale 4 and 5) of the students agreed that cognitive domain is important for them to identify, formulate and analyse the complex engineering problems. This is because complex problem solving requires the cognitive aspect to apply in-depth engineering knowledge at the level of one or more of fundamental knowledge, specialist knowledge, engineering design, engineering practices and literature research (Engineering Accreditation Council, 2020). A study on cognitive styles acquired by students indicated that high self-confidence and the ability to solve the problems are by designing the solutions through planning and making important decisions (Sutama et al., 2021).

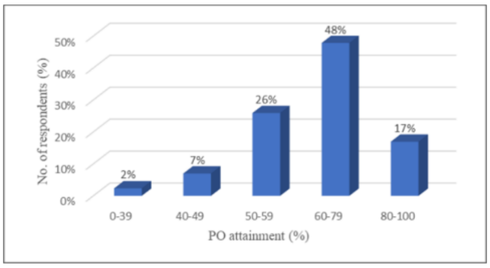

Fig. 4 Percentage Attainment for PO2

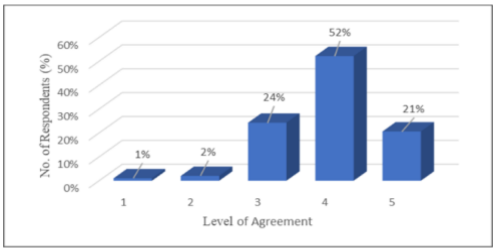

Fig. 5 Percentage Frequency Distribution on Importance of Cognitive Domain for PO2

Fig. 3 shows that the majority of the students obtained a score of more than 50% marks for the PO3 attainment with the highest frequency was at 60%-79% marks which was obtained by 48% of the students. Meanwhile, 12% of respondents had obtained a PO attainment with scores less than 50%. Similarly, to validate this PO3 attainment, the actual marks from the OBE system showed that the average PO3 score was about 70%. Fig. 7 illustrates the percentage frequency distribution on the importance of the cognitive domain to demonstrate the design solution for complex engineering problems. In this study, most of the students (56%) agreed that they must acquire the cognitive domain to deal with complex engineering problems which requires different levels of mental skills including knowledge, comprehension, application, analysis, synthesis, and evaluation (Bloom & David, 1956).

4.5 Factors Influencing Student's PO Attainment

This sub-section presents the result analyses for Section D of the questionnaires. Using a relative important index (RII), nine (9) statements related to factors influencing student's PO attainment was ranked (see Table 5). From the RII results, the most important or Rank (1) factor was "Guidance by the lecturers" (RII = 0.804) and followed by other factors of Rank (2) factor which was "Assignment and project given" (RII= 0.781) and Rank (3) factor which was "Time required to solve the complex engineering problem"(RII=0.77). Therefore, the students required more guidance or facilitations from the lecturers in order to excel in this PO.

Table 5. Ranking of Factors Influencing Students' PO Attainment using RII

Factors Influencing Students PO attainment with respect to Cognitive Domain	RII	Rank
Ability to solve the case study using given problem solving acquired during my study.	0.742	5
Use of latest engineering software such as Computer Aided Design (CAD) to solve the complex engineering problem.	0.748	4
Use of Numerical Analysis and Finite Element Method to determine the most optimum solutions to solve complex engineering problems.	0.738	6
The assignment and project given require identify, formulate, conduct research and analyse complex engineering problems.	0.781	2
Proper guidance by the lecturers have facilitated students to develop the solutions for the complex engineering problems.	0.804	1
Use computer software such as Finite Element Analysis (FEA) and others to perform the analysis on the complex engineering problems.	0.656	9
Self-motivated to solve the complex engineering problems because the non-obvious solutions that nurture creative and critical thinking that might occur from the analysis.	0.705	7
Challenge student ability to solve complex engineering problem compare to the normal engineering problem to design and develop the solutions.	0.685	8
Amount of time to solve the complex engineering problem depends on the complexity levels.	0.775	3

4.6 Intra-correlation between Factors Influencing PO Attainment

This sub-section presents the correlation analysis on the factors influencing the students' PO2 and PO3 attainment as shown in Table 6.

Table 6. Intra-correlation of Factors Influencing PO attainment

Variables	Apply knowledge	Latest Software	Related Subject	Exercise	**Lecturer Guidance**	Computer Analysis	Feel Motivated	Challenge Self-ability	Time Provided
Apply Knowledge	1	0.463	0.389	0.431	0.394	0.251	0.393	0.462	0.289
Latest Software		1	**0.648**	0.562	0.388	0.362	0.382	0.375	0.285
Related Subject			1	**0.575**	0.499	0.279	0.344	0.368	0.211
Exercise				1	**0.632**	0.207	0.311	0.384	0.276
Lecturer Guidance					1	0.28	0.326	0.378	0.350
Computer Analysis						1	**0.469**	0.450	0.360
Feel Motivated							1	**0.691**	0.454
Challenge Self-ability								1	0.422
Time Provided									1

As highlighted, Table 6 shows a large value and positive correlation relationship observed between "exercise" and "lecturer guidance's" factors ($r = 0.632$, $p < 0.05$). Thus, if "exercise" factor increases, the "lecturer guidance" factor also increases and vice versa. This means the students needed more practice through more exercises and practice to learn, where the increase in lecturer's guidance will help them to perform better to attain the required PO. The findings in this study show that the students' true attainment for PO2 was 64% while PO3 was around 70% which can be further improved. Thus, proper guidance by the lecturers may help to facilitate the students in improving their knowledge skills in problem analysis and develop the solutions for complex engineering problems. However, Liew et al. (2020) found that engineering educators have poor understanding of the attributes of complex engineering problems to construct design projects that simulate real industry scenarios. Thus, it is also expected that lecturers shall be competent and have good understanding of the CEP and CEA attributes to be able to design good projects for the students to practice.

5. Conclusion and Suggestion for Future Research

The cognitive aspect is believed to be one of the most important skills that must be possessed by students as future engineers and to prepare them to be competent in fulfilling the demands of industry. This study was conducted to determine the students' attainment level of cognitive skills in problem solving and design development based on an Integrated Design Project (IDP) and final year project (FYP) courses. Three hundred and one (301) final year students from four engineering schools have responded and provided their feedback on their PO attainment and the factors that contributed to their POs' attainment. The findings showed that most of the respondents believed that they had acquired the cognitive skills via culminating courses namely IDP and FYP. The findings also were further validated by using the actual marks obtained from the OBE assessment system. Thus, the results of the study could assist the lecturers and the university to enhance the cognitive skills in problem solving and design of solutions among the students. This study is limited to final year engineering students in one of the IHLs in Malaysia. Further research can be carried out on other universities' students on development of critical and problem-solving skills.

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