Efficacy of CDIO Approach and PjBL on the Performance of Final Year BTI Electrical and Electronics Engineering trainees

Subbiah Stalin, Bahrain Training Institute, Kingdom of Bahrain, phdstalin@gmail.com

Over the last decade there has been two dominating models for reforming engineering education: Project-Based learning (PjBL), and conceive–design–implement–operate (CDIO) initiative. PjBL encourages trainee to design, solve, and evaluate the real-world engineering problems and CDIO is an innovative initiative, which provides an alternative educational framework in producing highly skilled engineering graduates. By assimilating these two learning strategies, learners can acquire the skills that are required for the 21st century.

This paper evaluates the final semester unit "Engineering Project" of Level 3 Pearson BTEC Extended Diploma in Electrical & Electronics Engineering at Bahrain Training Institute (hereinafter called "BTI") in the settings of PjBL and CDIO approaches.

Two engineering projects namely "IoT Based Thermal Monitoring System for pervasive electric machine applications using ThingSpeak and ESP01" and "Automatic Plant Watering System" were used. Each project is being conducted for one full semester with 120 guided learning hours. Here the students will search, present their proposals and build prototypes whereby their 21st century skills are measured respectively. This paper discusses the effectiveness of CDIO approach and its relation with the existing project–based learning to identify and explain similarities and differences. Following an in-depth multi-dimensional analysis of preliminary findings, some recommendations for improving trainees' skills will also be presented.

***Keywords*:** Engineering Project; Design process; Project-based learning; CDIO and standards

Type of Contribution: Review/ conceptual paper

1. Introduction

According to preliminary evaluation of course “*Bahraini Perspectives”* at Bahrain Polytechnic, the Project Based Learning(PjBL) approach allow students to start from ‘where they are at’, and thus draw on their prior knowledge. It also allows them to share each other’s knowledge and co-construct their knowledge with their tutors and peers. Huijser, Henk & Wali, F. (2012).

Further to above, as part of strategy transformation plan, University of Bahrain is willing to shift from teacher-centred approached to other teaching strategies such as; project-based learning, problem-based learning, inquiry-based learning, evidence-based learning and e-learning. Each UOB college will develop its own learning and teaching philosophy that corresponds to the nature of its discipline and the industry requirements (Strategy Transformation Plan, University of Bahrain, 2016-2021).

Also under the theme-2 of Bahrain Higher Education Strategy (2014-2024), the future skills of Bahrain should integrate workforce readiness skills into higher education curriculum and student learning experience (National Higher Education Strategy, Higher Education Council, 2014-2024).

It is evident, that there were number of institutions who have taken the initiatives for changes in their curriculum (Graham, R. 2012).

Companies and society need engineers who possess a wide range of knowledge and skills as per the need of labor market and the need to venture successfully in a world that is changing at a rapid pace (Palma et al., 2012 and . Ramírez, M. 2009).

To be able to meet this demand, many strong alternatives curriculum change were used in higher engineering education, replacing mostly tried and tested theoretical concepts (Sheppard et al., 2009).

In this context, the Engineering education should be more inclusive, having a body of knowledge and skills that are based in basic appropriate competences such as competences in the main subject area and general competences about the activity and entrepreneurial and social contexts and the understanding of characteristics of future professionals (Kans, 2012) (Astigarraga, Dow, Lara, Prewitt, & Ward, 2010) (Andersen, Yazdani, & Andersen, 2007).

2. 21st Century skills:

21st century learning students should have (1) learning and innovation skills including critical thinking skills and problem solving, communication and collaboration, creativity and innovation; (2) information, media, and technology skills; and (3) life and career skills (Trilling & Fadel, 2009).

Therefore, various Engineering learning models in educational institutions are being developed to enhance students' skills; especially learner's creativity and critical thinking.

2.1 Creativity skills:

To face the challenges in the changing world, creative skills are highly required in education models (Kind & Kind, 2007). Questions, patience, openness to new ideas, high trust, and learning from mistakes and failures are used to enhance the creativity skills. (Trilling & Fadel (2009)). Creativity is a continuous process gained through practices. One of the most effective ways to develop creativity is by learning through projects in order to find solutions to real-world problems.

2.2 Critical thinking:

Engineering learning can be used to develop student's higher-order thinking skills which includes critical thinking. Interpretation, analysis, inference, evaluation, explanation, and self-regulation (Facione, 2011) are the elements of critical thinking. Critical thinking is denoted as higher-order level of thinking, which covers Bloom's Taxonomy components: the ability to analyse, synthesize, and evaluate (Bookhart, 2010; Moore & Stanley, 2010). Open- ended question or divergent questions can develop critical thinking skills. Open-ended questions are questions that expect many possibilities of correct answers (Collete & Chiappetta, 1994; Subali, 2013). One of the learning models that develop critical thinking skills especially in science is problem-based learning. Problem-based learning encourages students not only to think about the cause, but also how to solve the problems (Strobel & Barnevel, 2009).

To meet the 21st century skills, the learning models recommended by the present curriculum are Conceive, Design, Implement and Operate'' (CDIO), Project-Based Learning(PjBL), problem-based learning, discovery learning, and guided inquiry etc.

3. PjBL and CDIO Approaches:

In spite of the various pedagogical models, improvement in engineering education has gained more attention in recent years with two popular learning models, Problem Based Learning (PjBL) and 'Conceive, Design, Implement and Operate' (CDIO) (J. Dickens and C. Arlett, 2009 and S. Sheppard, K. Macatanguay, A. Colby, and W. Sullivan, 2009)

The PjBL does not come from one source or organization, but arises from the societal period with experimentations in the educational systems. PjBL practices that were established have developed into a sound theory of learning and is today well documented in all aspects of curriculum development, learning and competence development. Since the establishment of the PjBL universities, the PjBL models have been implemented all over the world. Especially the McMaster and the Maastricht models are utilized in health and law, whereas the Aalborg model with the problem based and project based/organized is most often used in variations in engineering and science (R.A. Eng.,2010 and P.L Linn, et al.,2011).

In PJBL, the real world problems are used to motivate the students through the problems (Farhan & Retnawati, 2014). Project based work actively encourages students to gather more in-depth knowledge of respiratory material and sharpen skills in research (Kean & Kwe, 2014). Project-based learning can enhance learning activities and student's creativity. It is also able to develop three learning domain namely cognitive, affective, and psychomotor (Sumarni et al., 2016).

"Conceive, Design, Implement and Operate'' (CDIO) promotes goal orientated, project based learning where the aims and desired learning outcomes are clearly stated prior to the students starting any project or before any instruction is given. It also promotes curricular reform to include design and build projects, to coordinate and link other subjects in an interdisciplinary engineering course. It aspires to create challenging experiences in which students design, build and operate product or systems. In addition, due to the innovative teaching styles, the initiative requires alternative assessment processes (Y. Zhan, L. Liang, et al., 2014, C. Norrman et al.,2014, E. F. Crawley, 2010, and CDIO Initiative, 2011).

At present, around 80 institutions in 25 countries are practicing CDIO approaches. In CDIO, Learning the fundamentals and the advanced disciplinary content on engineering is promoted, in an environment with clear references to the professional practice of engineering as an adequate context for learning.

There are three major objectives in CDIO: mastering a deep knowledge in fundamental techniques, leadership in the creation and operation of new products, processes and systems, and to understand the importance and the strategic impact of research and the technological development in society proposed through the development of standards and of CDIO's syllabus.

The CDIO syllabus defines competences that students should have when completing their training as engineers. These are the results of the confluence of the interests of all the parties involved in the engineering activity.

The competences of PjBL and first and second level of CDIO syllabus are shown in below table-1. The numbers used for each competence are used throughout this possible.

Table 1: Competences of PjBL and CDIO

PjBL	CDIO
The syntax of project-based learning by Bender (2012) are	**(1) Technical knowledge and reasoning**

(1) Planning the project (2) Gathering of information; (3) Creation, (4) Development, (5) Presentation, and prototype artifacts (6) Publication of product or artifacts 21st century skills such as (7) Problem solving (8) Communication (9) Collaboration, and (10) Creativity Markham (2012) indicated that PjBL "encourages the skills of the future-inquiry, collaboration, communication, and creativity- and critical thinking are designed to expand curriculum to encompass authentic issues and topics relevant to the needs of young people in a global world"	1.1) Necessary basic underlying knowledge in sciences 1.2) A body of knowledge of Fundamental Engineering 1.3) Knowledge of the fundamentals of Advanced Engineering **(2) Skills and personal and professional attributes** 2.1) Engineering reasoning and problem solving 2.2) Experimentation and knowledge discovery 2.3) Systemic thinking 2.4) Skills and personal attitudes 2.5) Professional skills and attitudes **(3) Interpersonal skills: teamwork and communication** 3.1) Teamwork 3.2) Communication 3.3) Mastery of a foreign language **(4) Conceive, design, implement, and operate systems in the business and social context** 4.1) The social and external context 4.2) The context of business and company 4.3) Conceive 4.4) Design 4.5) Implement 4.6) Operate

3.1 Relation between PjBL and CDIO in Engineering Project:

The development of Engineering Project aims to develop students' thinking skills, specifically critical thinking. Critical thinking skills are the ability to interpret data, make inferences, explain information clearly, analyse, and evaluate. However, student's critical thinking skills are not yet fully developed. Therefore, based on the demands of the 21st century, especially creativity and critical thinking, it is necessary to develop learning activities in schools that are able to enhance student's skills. Learning activities that are relevant to learning in the 21st century are project-based learning and problem based learning. Both models of learning are equally presented from the real world. Authentic issues presented at the beginning of the lesson are made into problems that must be solved by students either individually or groups.

Implementation of project-based learning in Engineering Project learning can be done by conducting project-based learning syntax written in lesson plans. The syntax of project-based learning by Bender (2012) are 1) introduction and team planning the project; 2) initial research phase in term of gathering information; 3) creation, development, initial evaluation of presentation, and prototype artifacts; 4) second research phase; 5) final presentation development; and 6) publication of product or artifacts. Problem-based learning is a teaching model using problems as the main focus for developing problem-solving skills, materials, and self-organization (Kauchak & Eggen, 2012). The problems used in this model of learning are real world problems (Arends, 2007; Fogarty, 1997). Problems encourage students to share knowledge, negotiate alternative ideas, seek information, and construct arguments to support established solutions (Sawyer, 2014).

Problem-based learning can be applied in learning Engineering Project by following syntax of the learning model. Problem-based learning begins with 1) problem orientation; 2) organizing students to conduct research; 3) assisting independent and group investigations; 4) developing and presenting artefacts; and 5) analysing and evaluating problem solving process (Arend,2007). During the learning activities, teachers play a role in providing problems, asking questions, and facilitating investigations and dialogue.

3.2 Objectives of the work:

The objective of the work is to evaluate the competences of PjBL and CDIO for the unit "Engineering Project" and at the same time, to demonstrate the improvement of learners' basic competences through statistical analysis that supports the conclusions presented at the end of the paper.

4. Materials and Methods:

The unit used in this research is “Engineering Project” and its two projects.

4.1 BTI Engineering Project Unit:

The unit titled “Engineering Project (EEE340/20539D)” is offered for the program “Level 3 Pearson BTEC Extended Diploma in Electrical & Electronics Engineering” by the Pearson Education limited, UK., with the aim of integrating knowledge and skills to BTI learners. This unit is a 20hour credit unit with 120 guided learning hours offered at the final semester of the qualification at Bahrain Training Institute, Kingdom of Bahrain.

The objectives set for the unit are: enable learners to specify, plan and implement an engineering project and present its outcomes. The learning outcome and its contents outline are shown in table-2

Table 2: Content of the unit engineering project

Learning Outcomes	Contents Outline
Be able to specify a project, agree procedures and choose a solution	Project records Initial concepts Specification Procedures Techniques
Be able to plan and monitor a project	Planning Monitoring
Be able to implement the project plan within agreed procedures	Implement Checking solutions
Be able to present the project outcome	Presentation Project report

The technical content of the unit consists of 4 learning outcomes designed from the “Edexcel BTEC Level 3 Nationals specification in Engineering – Issue 1 – January 2010 © Edexcel Limited 2009”.

The content provides learners with opportunities to present their own solutions to engineering projects or problems. The project is intended to develop the learner’s ability to identify and plan a course of action and follow this through to produce a viable solution/outcome to an agreed specification and timescale. The proposed solution may lead to some form of product or device. The end result could equally lead to a system of work, a process or a procedure or to a modification to an existing process or product. For learners studying the electrical/electronic pathway examples of project outcomes could include:

- Modification of an existing electronic/electrical product
- Specifying, designing and building an integrated hardware/software system
- Testing and evaluation of an electronic/electrical system or service
- Comparison and evaluation of a range of electronic/electrical CAD tools and systems.

Assessment of this unit will be based primarily on the learner's logbook/diary and other evidence of the work carried out and the processes adopted. Use will also be made of the learner's specification document, presentation and technical project report. The assessments designed for the course of projects are classified under three types: Report, Semester project and Presentation.

In a technical report, learners will need to include sketches, drawings/circuit diagrams, notes, lists, charts, raw calculations etc. to support their project report findings. These reports represent 50% of total evaluation.

Approval of the project proposals and project hardware/prototype represents 40% of the total assessment. Use of a range of computer software packages and electronic and prototype are necessary to both preparation and presentation of the project. The participation represents 10% of total evaluation. The Semester Project is in group/individual.

4.2 Engineering Projects Used:

This section discusses the two Engineering projects carried out by trainees in the final semester of training year 2019 for the program "Level 3 Pearson BTEC Extended Diploma in Electrical & Electronics Engineering".

4.2.1 Project 1: Automatic Plant Watering System Using Arduino Uno

Figure shows the experimental setup of the project. When a family goes on vacations, there will be no one to water the plants every day at home. Each plant needs water to survive. Therefore to solve watering issues to plant, an engineering project titled “Plant Watering System Using Arduino Uno” is proposed here. Moisture sensors are used to sense the moisture level of the soil and complete the action watering with help of programming in Arduino Uno. Arduino Uno is used as it has all the features that are needed for this project and the moisture sensor is used as it has more reliability than timer circuit. If soil gets dry, then sensor senses low moisture level and automatically switches ON the water pump to supply water to the plant with help of a signal from Arduino. As plant get sufficient water and soil gets moist, then the sensor senses enough moisture in the soil, after which the water pump will automatically stop. Water level sensors are also used to sense the level of the water tank. The system configuration of Automatic Plant Watering System is shown in fig.1

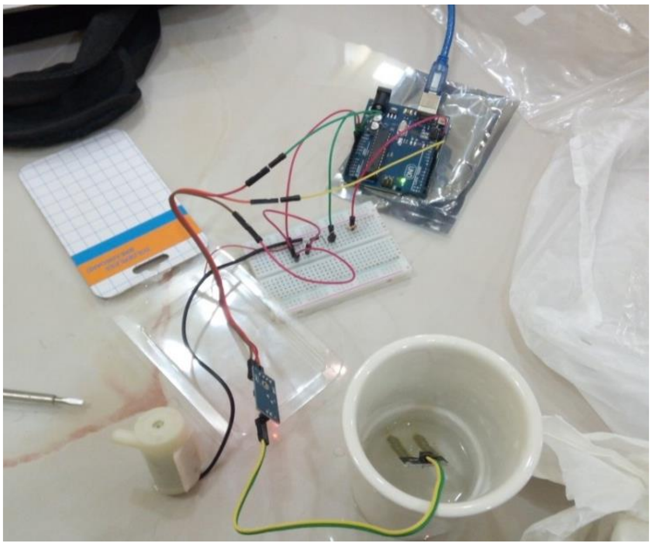

Figure 1: Automatic Plant Watering System on operation for demonstration

4.2.2 Project 2: IoT Based Thermal Monitoring System for pervasive electric machine applications using ThingSpeak and ESP01

This project titled “IoT Based Thermal Monitoring System for pervasive electric machine applications using ThingSpeak and ESP01” finds a solution for health check-ups of machine wirelessly and monitored remotely by an Arduino micro controller which is powered by solar energy. The project measures temperature of electrical machines/devices using wireless infrared sensors. The data is processed by an Arduino microcontroller, which is powered by solar panel and battery. The Arduino microcontroller suitably programmed and further interfaced with an ESP -01 WI-FI device. Suitable configuration of devices with IOT solution helps to remotely monitor the temperature of machines. The Arduino controller automates and takes necessary action when there is any increase of temperature above the set value. This project can be alternatively implemented to variety of applications interfaced with different types and number of sensors. The system configuration of IoT Based Thermal Monitoring System is shown in fig.2

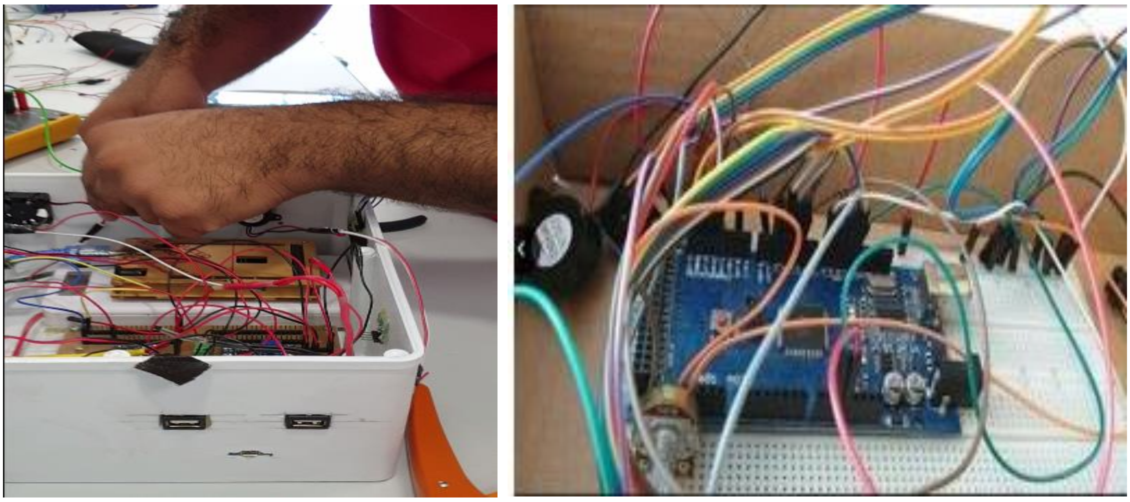

Figure 2: IoT Based Thermal Monitoring System

5. Results and Discussion:

The learning outcomes (LO) of engineering project are mapped with competences of PjBL and CDIO, as shown in table 3.

Table 3: Mapping of PJBL and CDIO for the unit Engineering Project

CDIO Syllabus	Pearson BTEC Learning Outcomes				PjBL Competences
	LO1	LO2	LO3	LO4	
1.1	C	P			1
1.2	C and P				2
1.3	P				3
2.1	C	P	P		4
2.2			C	P	5
2.3		C		P	6
2.4	P			C	7
2.5				C and P	8
3.1		C and P			9
3.2				C and P	10
3.3					
4.1	C				
4.2	C				
4.3	C				
4.4		C			
4.5			C		
4.6				C	

C-CDIO, P-PjBL

The basic competences among and between CDIO and PjBL are shown in the table 3. The similarities and differences are presented here. CDIO competence such as (3.3) Mastery of foreign language and (1.3) Advance Engineering fundamentals are not covered for the unit: Engineering Project. PjBL do not cover the operation of the project in terms of business and social context.

Table- 4 shows specific learning objectives, assessment methods and examples of PjBL and CDIO skills mapping of the Engineering Project Unit.

Table 4: Skills of CDIO and PjBL for the unit Engineering Project

Learning Outcomes	Assessment Types	PjBL as per BTEC	CDIO syllabus
Be able to specify a project, agree procedures and choose a solution	Log Book, Initial Report	IE-Independent learners TW-Team Workers EP- Effective Participators CT-Creative thinkers	1.1 1.2 1.3 2.1 2.3 3.1 3.3 4.1 4.2 4.3
Be able to plan and monitor a project	Log Book, Initial report	RL-Reflective Learner	4.4 2.2
Be able to implement the project plan within agreed procedures	Log Book, Final Report	SM- Self-Managers	4.5
Be able to present the project outcome.	Presentation, Final Report	SM- Self-Managers	2.4 2.5 3.2 4.6

Column 3 and 4 of Table 4, shows the skills comparisons between PjBL and CDIO for the Engineering project. The PjBL skills are as per the Pearson BTEC qualifications and CDIO skills are according first and second level of CDIO the unit evaluates several of the skills of the PjBL syllabus. It shows that most of the CDIO skills are available in PjBL; however few details in skills are missing which do not identifies opportunities for learners to demonstrate effective application of the skills.

Methodology of Analysis:

To evaluate the competences, the following research problem is presented: “Do the trainees have same competences level at the beginning and end of the Unit-Engineering Project?”. For this question, the null hypothesis with its respective alternate hypothesis is formulated as follows:

H_0: Competence (Begin of the unit) = Competence (End of the unit)

H_1: Competence (Begin of the unit) ‹ Competence (End of the unit)

“Pr (| H_1 | › | H_0 |) ‹ 0.05 confirms H_1:”; statistically significant difference,

“Pr (| H_1 | › | H_0 |) › 0.05 confirms H_0”; statistically significant no difference

For statistical analysis, “t-test for two paired” test is conducted using the statistical tool Stata/IC 12. The hypothesis set for each of the 17 competences of the first and second level of CDIO syllabus and PjBL are shown in the below table-5

Table 5: Statistical Analysis for skills improvement

CDIO Competences	Before	After	Pr (| H_1 | › | H_0 |)	Pr (| H_1 | › | H_0 |)	After	Before	PjBL Competences
1.1	3.66	4.66	0.000	0.000	4.66	1.66	1
1.2	3.00	4.00	0.000	0.667	3.66	3.33	2
1.3	3.00	4.66	0.935	0.963	4.33	2.00	3
2.1	2.00	4.66	0.992	0.566	3.33	3.00	4
2.2	2.33	4.66	0.990	0.000	3.33	3.33	5
2.3	2.00	4.00	0.962	0.000	4.33	2.33	6
2.4	1.66	4.33	0.992	0.000	4.33	2.33	7
2.5	3.00	3.33	0.787	0.962	3.66	1.66	8
3.1	3.66	4.33	0.908	0.990	3.66	1.33	9
3.2	3.33	3.33	0.000	0.935	3.66	2.00	10
3.3	2.66	2.66	0.000				
4.1	4.00	3.66	0.211				
4.2	3.66	3.66	0.500				
4.3	4.00	4.66	0.908				
4.4	2.66	5.00	0.963				
4.5	2.66	4.66	0.962				
4.6	2.00	5.00	0.000				

Note: “Final Score scale is 1-5”

The table-5 shows that, for the research problem, the CDIO competences (1.1, 1.2, 3.2, 3.3 and 4.6) and PjBL Competences (1, 5, 6, 7) are equal to 0 value, confirms with regard to alternate hypothesis asserting that there is **significant improvement of the competences**, before and end of the unit "Engineering Project"

The other CDIO competences (1.3, 2.1, 2.2, 2.3, 2.4, 2.5,3.1 and 4.3-4.5) and PjBL competences (3,8,9 and 10), shows trainees competences are at the same level whereas competences like 4.1, 4.2, 2 and 4 shows that there was a significant decline in the performance.

6. Conclusions and Future Plans:

In this paper, the preliminary use of CDIO syllabus and PjBL competences has been discussed by taking into the account of final semester unit "Engineering Project" of Level 3 Pearson BTEC Extended Diploma in Electrical & Electronics Engineering at Bahrain Training Institute.

It was shown that the two projects carried out by learners helps them to formulate problems and provide engineering solutions, and the learners were able to explore engineering project concepts effectively. It is evident from the submitted technical reports and final grades.

At the mid of the study, it was found that implementation of CDIO syllabus initiative in BTI curriculum can increase the mastery of foreign language and advance engineering fundamentals. PjBL do not cover the operation of the project in terms of business and social context.

The competences of CDIO are more in-depth, clear and specific in assessments, which is the basis for the development and improvement of 21st century skills. It was found that, CDIO syllabus covers all the 21st century skills when comparing to the PjBL skills set by Pearson BTEC qualifications. Learners' assessment components can increase their creative and critical thinking.

The statistical analysis of learners CDIO and PjBL competences, before and end of the unit: Engineering project shows significant improvement in their creative and critical skills. Competences like 4.1, 4.2, 2 and 4 shows that there was a significant decline which means social and business context are lacking in the side of learners. It can be solved by introducing CDIO syllabus in the unit. The implementation of CDIO syllabus will show that they are worth investing in engineering setup.

In future, a more systematic study would be carried out to gauge the effectiveness of the CDIO concept using Engineering projects. All the course should reflect CDIO standards with the objective of improving content of learning and learning outcomes. The following recommendation are put forward:

1. Selection of project based on social and business context and the actual problem must be deliverable
2. Link to other units to attain knowledge on advance Engineering.
3. Presentation should be completed before the written report is submitted which adds advantage of being able to inform the learner of any additional considerations that may need to be taken into account in order to improve the worth of the final project solution.

References:

Huijser, Henk & Wali, F. (2012). A PBL Approach to Teaching Bahraini Perspectives at Bahrain Polytechnic. 10.13140/2.1.5010.6249.

http://www.uob.edu.bh/en/images/About_UOB/Strategy-Transformation_Plan_2016-2021.pdf

http://www.moedu.gov.bh/hec/UploadFiles/Bahrain%20Higher%20Education%20Strategy%20-%20Summary.pdf

Graham, R. 2012. *Achieving Excellence in Engineering Education: The Ingredients of Successful Change*. London: Royal Academy of Engineering.

Palma, M., De los Ríos, I., Miñán, E., & Luy, G. (2012). Hacia un Nuevo Modelo desde las Competencias: laIngeniería Industrial en el Perú. *Tenth LACCEI Latin American and Caribbean Conference.* Panama:LACCEI.

Ramírez, M. (2009). La importancia del desarrollo de competencias del futuro ingeniero. *3er Foro Nacional de ciencias básicas: formación científica del ingeniero.* México D.F.: Universidad Nacional Autónoma de México.

Sheppard, S., K. Macatangay,A. Colby, andW. M. Sullivan. 2009. *Educating Engineers: Designing for the Future of the Field*. San Francisco, CA: Jossey-Bass.

Kans, M. (2012). Applying an innovative educational program for the education of today's engineers. *Journal ofPhysics: Conference Series 364*.

Andersen, N., Yazdani, S., & Andersen, K. (2007). Performance Outcomes in Engineering Design Courses.*Journal of professional issues in engineering education and practice*.

Astigarraga, T., Dow, E., Lara, C., Prewitt, R., & Ward, M. (2010). The Emerging Role of Software Testing in Curricula. *Transforming Engineering Education: Creating Interdisciplinary Skills for Complex Global Environments.* Dublin: IEEE.

Trilling, B., & Fadel, C. (2009). 21st Century Skills: Learning for Life in Our Times. San Francisco, CA: John Wiley & Sons.

Kind, P. M., & Kind, V. (2007). Creativity in Science Education: Perspectives and Challenges for Developing School Science.

Facione, P. A. (2011). Critical Thinking: What It is and Why It Counts. California: Measured Reasons and The California Academic Press

Brookhart, S. M. (2010). How to Assess Higher-Order Thinking Skills in Your Classroom. Alexandria: ASCD

Moore, B., & Stanley, S. (2010). Critical Thinking and Formative Assessment: Increasing The Rigor in Your Classroom. Larchmont: Eye on Education Inc.

Collelete, A.T., & Chiappeta, E.L. (1994). Science Instruction in The Middle and Secondary School. New York: Macmillan Publishing Company.

Subali, B. (2013). Kemampuan Berpikir Pola Divergen dan Berpikir Kreatif dalam Keterampilan Proses Sains: Contoh Kasus dalam Mata Pelajaran Biologi SMA. Yogyakarta: UNY Press.

Strobel, J., & Van Barneveld, A. (2009). When Is PBL More Effective? A Meta-Synthesis of MetaAnalyses Comparing PBL to Conventional Classrooms. Interdisciplinary Journal of Problembased Learning, 3(1), 4.

J. Dickens and C. Arlett, 2009. Key Aspects of Learning and Teaching in Engineering'. In Fry, H., Ketteridge, S., & Marshall, S., (eds). A Handbook for Teaching and Learning in Higher Education. Chpt 18. pp 264-281. London. Routledge.

S. Sheppard, K. Macatanguay, A. Colby, and W. Sullivan, 2009, Educating Engineers. ‘Designing for the Future of the Field’, A report of the Carnegie Foundation for the Advancement of Teaching, San Francisco, Jossey Bass.

R.A. Eng. (2010). ‘Engineering the Future: A Vision for the Future of UK Engineering’’, London. Royal Academy of Engineering.

Farhan, M., & Retnawati, H. (2014). Keefektifan PBL dan IBL ditinjau dari Prestasi Belajar, Kemampuan Representasi Matematis, dan Motivasi Belajar. Jurnal Riset Pendidikan Matematika, 1(2), 227-240

Kean, A. C., & Kwe, N.M. (2014). Meaningful Learning in the Teaching of Culture: The Project Based Learning Approach. Journal Of Education and Training Studies, 2(2), 189-197

Sumarni, W., S. Wardani, S., Sudarmin, & D. N. Gupitasari. (2016). Project Based Learning (PBL) to Improve Psychomotoric Skills: A Classroom Action Research. Jurnal Pendidikan IPA Indonesia, 5, 2, 157- 163

P.L Linn, A. Howard, A. and E. Miller, 2011. Handbook for Research in Cooperative Education and Internships. Taylor &Francis (2011).

Y. Zhan, L. Liang, X. Lan, J. Zhu, and Q. Lin, ‘Research on a CDIO-based practical teachingsystem in a Logistics Engineering major’,World Transactions on Engineering and Technology Education, 2014.

C. Norrman, D. Bienkowska, M. Moberg, and P. Frankelius, "Innovative methods for entrepreneurship and leadership teaching in CDIO based engineering education," in 10th International CDIO Conference, 15-19 June 2014, Barcelona, Spain, 2014.

E. F. Crawley, 2010, ‘The CDIO Syllabus. A Statement of Goals for the Undergraduate Engineering Education’. MIT CDIO Report #1.

CDIO Initiative, (2011), “CDIO Initiative Homepage”, www.cdio.org, 2011, accessed on 5th June 2015.

Markham, T. (2012). Project based learning: Design and coaching guide. San Rafael, CA: HeartIQ Press

Arends, R. (2007). Learning to Teach: Belajar Untuk Mengajar.Yogyakarta Pustaka Pelajar.

Bender, W. N. (2012). Project-Based Learning: Differentiating Instruction for the 21St Century. California:Corwin.

Fogarty, R. (1997). Problem-Based Learning & Other Curriculum Models for the Mutiple Intelegences Classroom.Glenview: Sky Light Proffesional Development.

Kauchak, D., & Eggen, P. (2012). Strategi dan Model Pembelajaran: Mengajarkan Konten dan Keterampilan Berpikir. Jakarta: Indeks.

Sawyer, R. K. (2014). The Cambridge Handbook of The Learning Science Second Edition. New York:Cambridge University Press.

Pearson BTEC Level 3 Diploma and BTEC Level 3 Extended Diploma in Electrical/Electronic Engineering (QCF),June 2016, Issue 2ISBN 978 1 446 934654