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A BLUEPRINT FOR AN INTEGRATED PROJECT BASED LEARNING FRAMEWORK IN ENGINEERING EDUCATION: A CASE STUDY AT TAYLOR'S UNIVERSITY

MUSHTAK AL-ATABI, EDWIN CHUNG*, SATESH NAMASIVAYAM, ABDULKAREEM SH. MAHDI AL-OBAIDI, MARWAN M. SHAMEL

School of Engineering, Taylor's University, No. 1 Jalan Taylor's
47500 Subang Jaya, Selangor DE, Malaysia
*Corresponding Author: ChinYau.EdwinChung@taylors.edu.my

Abstract

As a means to produce highly sought after graduates, education institutions are now turning to Project-Based Learning (PjBL). The road to a successful implementation of PjBL at the institutional level is lined with challenges and has deterred many. One of the major challenges is the number of projects needed to sustain such an implementation. As a means to overcome this, an integrated PjBL framework is proposed. It is observed that this framework makes it very obvious to staff working on a research project that they could leverage on students in the various design modules by carving out different aspects of their research projects into smaller projects that could be offered as student projects. In doing so, staff research workload and the need to develop projects to support PjBL are no longer seen as separate workload but are synergistic.

Keywords: Project-based learning, Integrated framework, Talent farm.

1. Introduction

Engineering is a profession where the ability to apply technical principle while remaining human with effective interpersonal skills is extremely important. While engineering principles are taught in class, the ability to apply these principles and interpersonal skill are learned and sharpened in projects. Today, Project-Based Learning (PjBL) is widely accepted as a means to develop competent graduates especially in the engineering and technology fields [1-4]. This is especially so when projects offered are current, industry linked and/or research driven. Initiatives, such as the CDIO (Conceive, Design, Implement, Operate), provides a framework to educate engineers using a curriculum that mirrors the product development and deployment lifecycle [5].

The Engineering Accreditation Council of Malaysia (EAC), (Malaysia being a signatory of the Washington Accord) highlights the necessity of PjBL by dedicating a Programme Outcome to this pedagogy as follows:

EACs Generic PO; PO number 3.

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 [6].

As such, all Malaysian Institutions of Higher Learning (that offer Engineering Programmes) would need to map their own programme outcomes to that of EACs and as such by default would need to address PjBL in their curriculum.

However, institutional implementation of PjBL is not a straightforward process as it is often confronted with obstacles such as faculty available time and skills, resources requirements as well as space. These are not trivial obstacles and addressing them is crucial for the successful implementation of PjBL.

This paper describes a framework that would allow an institution to implement PjBL in a sustainable manner through integrating the projects and offering them through research groups allowing for alignment between research and teaching duties of staff as well as providing the senior students with leadership opportunity to help in training and mentoring of their juniors working on a related project. Although this paper draws heavily on the experience of Taylor's University, the challenges faced and the potential opportunities are believed to be similar and easily extrapolated into other institutions.

This paper is organised as follows. The way in which PjBL is implemented at Taylor's School of Engineering and their relevant modules are first described. Difficulties experienced in such an institution wide adoption of PjBL are next described. Finally, a blueprint for integrated project-based learning framework is detailed.

2. Taylor's Engineering Programmes Structure

Taylor's School of Engineering offers three undergraduate programmes in the chemical, electrical & electronic and mechanical engineering disciplines. The syllabus of each of these programmes consists of a number of core and elective modules designed in such a way as to provide graduates with a solid foundation in the principle of engineering of the respective discipline as well as specific topics in areas that are current and highly sought after.

The school embraces the PjBL philosophy and delivers it through a series of project-based design modules from semester 1 to semester 8. These modules are offered to all engineering students as core module and their Learning Outcomes are outlined below.

- **Engineering Design and Communication**

This module is offered to first semester students from all the engineering programmes and it aims to introduce the basics of engineering design principles

and its related skills. It aims also to provide technical communication skills such as reporting, sketching and drafting. On completion of this module, students will be able to:

1. Explain the social, cultural, global, ethical and environmental responsibilities of a professional engineer;
2. Use reverse engineering to infer how a given device works
3. Adopt team-working strategies;
4. Critique different design ideas, comparing and evaluating them
5. Write effective technical reports and updated logbooks;
6. Produce clear and accurate sketches and drawings (both manual and computer generated).

- **Engineering Design and Ergonomics**

This module is offered to all engineering students in the second semester in order to equip them with the knowledge and skills related to human factor engineering. Students are required to apply these skills working on a major team design project that involves human-machine interaction. On completion of this module, students will be able to:

1. Explain the importance of interactions in human-machine systems;
2. Identify and analyse necessary design features related to product design;
3. Assess risk, health and safety, and environmental issues related to design projects;
4. Evaluate design based on ergonomic principles.

- **Multidisciplinary Engineering Design**

This module is offered to all third semester students to familiarize them with real-life work environments where engineers from different disciplines and backgrounds work together to realise a given task. On completion of this module, students will be able to:

1. Explain the principles of design for sustainable development;
2. Apply the principles of physics to achieve a specific engineering task or to build an engineering artefact;
3. Evaluate different approaches to achieve a required end result
4. Appraise and defend ideas;
5. Predict outcomes of suggested approaches;
6. Explain the benefits and barriers associated with multidisciplinary teams.

- **Engineering Design and Innovation**

This module is offered to all semester four students with the aim of introducing design thinking as part of the engineering design process and the process of commercialising a product. On successful completion of this module, students will be able to:

1. Apply and incorporate the technique of understand, observation, ideation and prototyping as part of the design process;
2. Explain the importance of business value in design and innovation and to be able to estimate them;
3. Explain the importance of intellectual property rights as a legal instrument for commercial monopoly;
4. Use appropriate communication techniques to communicate concepts and ideas;
5. Explain the non-technical aspect related to commercialising a product.

- **Managing Projects for Success**[1]

This module is offered to all semester 4 students and allows them to apply and evaluate project management tools and techniques in managing their Engineering Design and Innovation project to reach its goals and targets. On successful completion of this module, students will be able to:

1. Define what a successful project is;
2. Explain project management process groups;
3. Apply techniques to manage and balance scope, schedule, cost, resources and other aspects of a project;
4. Evaluate the success or failure of a project.

- **Group Project 1 and 2**

Offered during semester 5 and semester 6, Group Project 1 and 2 modules represent opportunities for students from different programmes to work on a fairly complex disciplinary specific project with peers from their respective programme. This is necessary to allow specialisation and disciplinary skills to develop.

- **Final Year Project 1 and 2**

These modules are offered to the final year students and represent the climax of the project based experience where a student will individually work on a major, research based engineering project. Working closely with a project supervisor, these two modules represent an opportunity for the students to develop high-level research and analytical skill. Students need to have work of a publishable standard.

3. Challenges

In many cases, the projects offered to the students in a PjBL environment depend on the lecturers' expertise and imagination. Students' interests and contemporary issues are also taken into consideration [7]. If a School is planning to implement PjBL throughout its programmes, and assuming a 5 student per project group, a

[1] This module in its operation does not require an engineering project as an outcome, however it plays an important progressive component in providing students with the necessary tools and techniques to further enhance the management of their projects in relevant PjBL modules. As such this module is not highlighted in the framework.

1000 students school will require in the order of 350[2] different projects. This mass offering of projects may result in a lack of focus and will be very taxing on the resources of the School as well as the time of the academic staff. Schools commonly mitigate this by either offering the same project to an entire cohort of students or limit the PjBL to only senior years in the programme. Both approaches may not be ideal and have their shortcomings.

Frequently, a good project worked on by a project team had to be transferred to a new team unfamiliar with the project or be suspended as the previous team progresses through to a design module where its learning outcome is not aligned with the project itself. As an example, a team of students working on the treatment of palm oil effluent while they are enrolled in the engineering design and communication module in semester 1 will have a tough time working on the same project in semester 2 as the engineering design and ergonomics module in semester 2 has an emphasis on human factor and ergonomics.

Though industry linked projects are not uncommon, with the exception of final year projects, sizeable industry linked and/or research driven projects are generally not the kind of projects that can be supported by these undergraduate design modules. This is an irony as you would expect sizeable projects to be able to benefit a larger group of students.

To overcome these challenges and to capture the potential benefits of those sizeable industry linked and research driven projects, an integrated PjBL framework is proposed.

4. Integrated PjBL Framework

The framework proposed here approaches this challenge differently through offering carefully selected strategic projects. Different research groups at the school are encouraged to propose major projects that can have different groups of students working on different parts of the projects simultaneously. For example, the Energy Research Group offered a project to design, build and race a solar car. The project supervisory team would work closely with the PjBL modules coordinators (semester 1 to 8) to break this project down into components that can be offered to students from semester 1 through semester 8, and even beyond that extending the project to postgraduate level, whenever appropriate. Project supervisors and modules coordinators ensure that the sub-projects offered are of adequate standards and suitable to enable students to achieve the learning outcomes of the specific module they are registered for.

4.1. Project criteria

For a project to fit in this framework, it needs to be complex enough to have multiple components that can be offered to different groups of students at different semesters to work on. It is necessary that components of appropriate complexity and difficulty are assigned to students at different levels of their studies. Some projects may not allow for all the sub-projects to be offered

[2] This figure assumes that about a quarter of these 1000 students will be working on individual projects in their final year, while the remaining divided into teams of 5.

simultaneously, instead they need to grow over time allowing the prerequisite projects along the critical path to be completed in sequence.

Projects that can be repeated will have an added advantage. For example, a car development project can always be repeated to build another improved car. This will allow the knowledge and skills accumulated to be built upon by future teams. Projects that emanate from the research interest of academic staff research groups are also highly desirable. This is especially true when the project supports one of the Grand Challenges for Engineering [8]. Projects that are both aligned to the Grand Challenges and the academic staff research interest have a higher chance of successful completion as they have a clear higher purpose that motivates the students (addressing a Grand Challenge) as well as being aligned with academic staff interest and expertise.

4.2. Projects Organisation

The sub-projects are offered in such a way that as a project matures; the senior students will play a growing role in mentoring their juniors enabling the seniors to develop leadership skills and allowing for different parts of the project to be integrated. This encourages peer learning which is a powerful learning tool [9] increasing the success rate of the project and reducing the time required to supervise students by the academic staff. The process of projects development and integration is as follows

i. The project supervisor identifies project(s) of interest based on the criteria above. This project is to be presented to the PjBL Committee for feedback and endorsement. This is to ensure that the project meets the development criteria, is aligned with School priorities and also to reduce the chance of having repetitive projects.
ii. After the project is endorsed by PjBL Committee, the project supervisor identifies suitable sub-projects for each semester (1-8) based on the Learning Outcomes of the Design Module offered at the respective semester. Depending on the project, certain Design Modules may have more than one sub-project while other Design Modules may have none.
iii. In discussion with the module coordinator, the project supervisor prepares a brief for the sub-project(s) identifying the deliverables and the assessment rubrics and clearly linking the deliverables to the respective Learning Outcomes.
iv. If the senior students are required or expected to mentor or supervise their juniors, this should be clearly stated in the project's deliverables.

Table 1 shows a snap shot of the integrated PjBL matrix. The left column shows all the main projects offered at a given time. Each main project will have a running serial number starting with 1. The row corresponding to each main project contains the sub-projects. Below is the list of sub-projects corresponding to the main project 1.

1.2.1 CDIO of Driver's Seat of a Petrol Racing Car
1.2.2 CDIO of Improved Driver's Suit for Petrol Racing Car
1.2.3 CDIO of Improved Driver's Helmet

1.3 Evaluation and Improvement of the Design of 2010 Racing Car
1.4 Fund Raising for Taylor's Racing Team
1.5 and 1.6 CDIO of Manufacturing Facility with 500 Racing Car per Year Capacity
1.7 and 1.8 CFD of Improved Racing Car Styling

For each sub-project, the project supervisory team develops a "project brief" describing its objective(s) and deliverables and linking it to the main project. The deliverables are closely aligned to the Learning Outcomes of the design module. Rubric for the assessment of deliverables is given as well. As mentioned earlier, this is to be discussed and agreed upon by the module coordinator. A "project brief" is shown in Table 2.

Though the Integrated PjBL Framework was described above from the view the School's research groups, this framework is also applicable for industry linked projects in the same manner. Such industrial linked projects may still be offered by a research group or other specially setup centre that solicits projects from the industry.

Table 1. Integrated PjBL Matrix.

Projects	Project Serial Number	Project Supervisor	Semester							
			1	2	3	4	5	6	7	8
			Eng. Design & Com. Module Coordinator	Eng. Design & Ergo. Module Coordinator	Multidisc. Eng. Design Module Coordinator	Eng. Design & Inno. Module Coordinator	Group Project 1 Supervisor	Group Project 2 Supervisor	FYP 1 Supervisor	FYP 2 Supervisor
CDIO of a Petrol Racing Car	1			1.2.1 1.2.2 1.2.3	1.3	1.4	1.5	1.6	1.7	1.8
CDIO of a Solar Racing Car	2			2.2	2.3	2.4	2.5	2.6	2.7	2.8
CDIO of a UAV	3			3.2	3.3	3.4	3.5	3.6	3.7	3.8
CDIO of a Model Solar Boat	4		4.1							
CDIO of a Full Size Solar Boat	5									
CDIO of a Hovercraft	6									
CDIO of Brain Operated Wheel Chair	7									
CDIO of a Computing Device	8									
CDIO of a Chemical Car	9									
CDIO of a Human Power Vehicle	10									
CDIO of Robot	11									
CDIO of a Solar Farm	12									
CDIO of a Water Purifier	13									
CDIO of a Wind Turbine	14									
CDIO of Production of Biodiesel	15									

CDIO of Biomass Energy	16									
CDIO of Electric Car	17									
CDIO of Electric Tri-Cycle	18									
CDIO of Natural Building Materials	19									
CDIO of Better Medicines	20									
CDIO of Tools of Scientific Enquiry	21									
CDIO of Ergonomic Furniture	22									
CDIO of a Car Race	23									
CDIO of Solar Boat Race	24									
CDIO of a Low Cost High Quality Lecture Capture System	25									
CDIO of Products and Systems for the Golden Years	26									

Table 2. A Project Brief Template.

Module		
Main Project		
Sub-Project		
Research Group		
Grand Challenge		
Supervisor(s)		
No of Students		
Budget		
Date		
Project Description		
Project Deliverables	LO	Assessment

4.3. Project Assessment

The project supervisor (or supervisory team) is expected to provide guidance and support to the students working on his (her) project. This includes regular meetings with the students to track the progress of the projects. The module coordinator (and the support team if any) is responsible for the assessment of the students working on different projects. This is necessary to ensure that the

assessment is fair, reflective of the achievement of the Learning Outcomes and consistent across the cohort of students regardless of the project.

In order to assist the module coordinator in ascertaining on whether students have achieved the associated Learning Outcomes, the school uses an Outcome Based Education (OBE) software tool that is able to calculate the specific Learning Outcome (LO) attainment of an individual student in the module. Such results are useful in evaluating the success of the module through its delivery techniques that has aided on enhancing the overall student learning experience by ensuring a majority of the students have achieved the associated Learning Outcomes. The results obtained would also be used to further enhance the module in the spirit of Continual Quality Improvement (CQI).

5. Discussion

It is recalled that 3 challenges were cited earlier pertaining to the implementation of PjBL at an institutional level. These are

i) The large number of projects that would be required to sustain an institution wide implementation of PjBL,

ii) Sizeable industry linked projects may not be scope in a manner that can be supported by project/design syllabus, and

iii) The sequence of these project/design modules may not match the development sequence of certain projects.

This does not mean that these are the only challenges you will face when implementing PjBL at an institutional level, but these are the 3 challenges that the Integrated PjBL Framework detailed above was designed to resolved.

The need for large number of projects is taken care of essentially by aligning and scoping projects from the School's Research Groups. The benefit to these Research Groups is the access to a large pool of students to assist with the groups' research. In return students get to work on current research driven projects. Sizeable industrial linked projects are scope automatically to fit the underlying project/design modules in the way project are organised as sub-projects that are aligned with the learning outcome of these modules. This still leaves us with the matching between the sequence of the project/design modules and the progression for some projects. Here, one may be tempted to design the underlying project/design modules with loose learning outcome that will fit the scope of most projects. The danger here is that the quality of the design curriculum may be weakened in the process. To overcome this, the following is proposed.

Project/design modules during the senior years (year 3 & 4) are discipline specific and spread over 2 semesters making it fairly easy to accommodate sizeable industry linked and research driven projects. Mismatches between the learning outcomes of these modules and the progression of the projects are less likely to occur. Also, as there are no real perquisites for the design modules from semester 2 to 4, these mismatches can be circumvented by allowing students to enrol for these modules in the sequence that matches the progression of the project. The implication is that the timetabling of these related modules had to be such that they are all scheduled at the same time.

- **The Instrument for a Talent Farm**

Taylor's School of Engineering has an initiative to one day be free from reliance of student fees and that each graduating cohort will have zero impact on the job market. In other words, there will be a mechanism and a demand for our students that their tuition fees are sponsored by the industry and some of our graduates will become entrepreneurs creating jobs instead of having all our graduates needing and seeking jobs form the economy. This initiative is known internally as *the journey to zero*. A key element to the success of this lies in our ability to produce quality graduates that are highly sought after. Apart from the design of our curriculum, PjBL is a critical component and the ability to sustain PjBL in the school and to feed it with current industry linked and/or research driven projects is crucial. To achieve this, Taylor's Technology Innovation Centre, the innovation centre for the School forms linkages with the industry and draws from this linkages industry linked projects. These projects are then awarded to talented students within the school with the intention of grooming them into technopreneurs.

Though institutions considering PjBL may not be considering setting up a talent farm, the authors felt that it is important to share this vision and approach so that to make the a more complete write up.

6. Conclusions

This paper presents a blueprint for an integrated project-based learning model which has the aim of ensuring sustainability by offering complex engineering projects, which solutions can be addressed through a variety of modules. The models are further enhanced through the schools ability to track the Learning Outcomes attainment of a student as they progress throughout each module and provide an avenue for the school to further enhance its delivery, ensuring the learning experience of the student continues to progress and evolve.

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