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Crafting a Real-World Problem Project-Based Learning Based on Gantry Crane System

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ABSTRACT

This paper presents the design and implementation of project-based learning for the System Modeling and Analysis course using a real-world gantry crane system problem in the first control engineering course for electrical engineering students. This project-based approach covers several topics including modeling, simulation, control and analysis. Several activities were conducted as part of the implementation of this project-based learning to achieve the intended learning outcomes of the course and the students' expectancies values such as attainment, intrinsic, and utility values. Both individual and group assessments were performed to evaluate the abilities and knowledge, as well as to observe and provide feedback on the development of the required skills. The impact of this project-based learning implementation is evaluated by analyzing students' feedback comments and suggestions. The findings indicate that students' can develop their ability to solve a practical problem systematically as well as enhance their understanding and motivation towards learning. Hence, this indicates that all expectancy values considered are achieved.

1. Introduction

Generally, the traditional learning process in control engineering courses is dominated by the examination. It typically involves providing students with fundamental and theoretical knowledge throughout the semester, and then evaluating their mastery of the course through a series of summative assessments including the tests, quizzes, and the final examination. With the current challenges requiring engineers to develop skills such as the lifelong learning, the critical thinking, the communication, and the decision making, the traditional way of learning may no longer be appropriate for future engineers [1]. These such values of outcome requirement are conducted in this study using project-based learning (PjBL) activities with specific intended learning outcomes (ILOs).

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The PjBL has been considered as a good approach in improving engineering education because it facilitates the learning of difficult courses and encourages an active learning. It also allows for the development of both engineering knowledge and generic or soft skills through the use of a 'learning environment that simulates a real professional challenge' which suits the criteria of CTL in researches by Fernández-Samacá *et al.,* [2] and Mahasneh and Alwan [3]. A comprehensive review of PjBL implementation at the university level has been discussed by Le [4]. Al-Sharif [5] proposed a generic framework of PjBL is designed for the general control engineering course. Several PjBL have been conducted for the control engineering courses with crane systems such as in Correia *et al.,* [6], Jayaram [7] and Yuan and Shen [8]. PjBL is also expected to create a better engineer for 21st century as mentioned in Noordin *et al.,* [9] and Sanger and Ziyatdinova [10]. Not limited to the control engineering courses, the PjBL has been used with a remarkable success in several basic engineering courses including the Astrodynamics by Jayaram [11], the Instructional System Design by Xiaoxiong [12], the Embedded Systems by Sababha *et al.,* [13], the Biomaterials by Jeon *et al.,* [14], and the Product Design by Zancul *et al.,* [15]. Moreover, PjBL has a profound impact on both students and lecturers, benefiting them in various ways. The implementation of PjBL enhances students' and teachers' self-efficacy, as elaborated in the study conducted in Choi *et al.,* [16], and Bilgin *et al.,* [17]. When designing the PjBL, several aspects should be taken into account such as the learning outcome, students' prior knowledge, and topic covered. To avoid wasted effort and frustration to the project outcome, a systematic framework is structured to ensure that the project design met the defined objective.

An expectancy-value theory is an example of a systematic framework that can be utilized to design a project. An expectancy model of achievement's performance and choice in the mathematics accomplishment domain have been proposed for task-specific beliefs, such as the ability beliefs, the perceived difficulty of different tasks, the individual objectives, self-schema, and the affective memories. Those are thought to influence the expectations and values [18-20]. Expectancy is a person's expectation on how well he or she will do on impending tasks. The values can be divided into four components which are the attainment value, the intrinsic value, the utility value, and the cost. Wigfield *et al.,* defined the attainment value as the significance of performing well on a given task; the intrinsic value is the pleasure derived from completing a task; the utility value is how a task fits into a person's long-term plans; and the cost is how the decision to participate in one activity is made as the limits access to other activities. In this paper, this framework is presented to support the instructor in designing an appropriate and effective PjBL for an undergraduate electrical engineering course (the System Modelling and Analysis). The framework is shown in Figure 1. In this PjBL, only the three values have been considered as shown in the following figure.

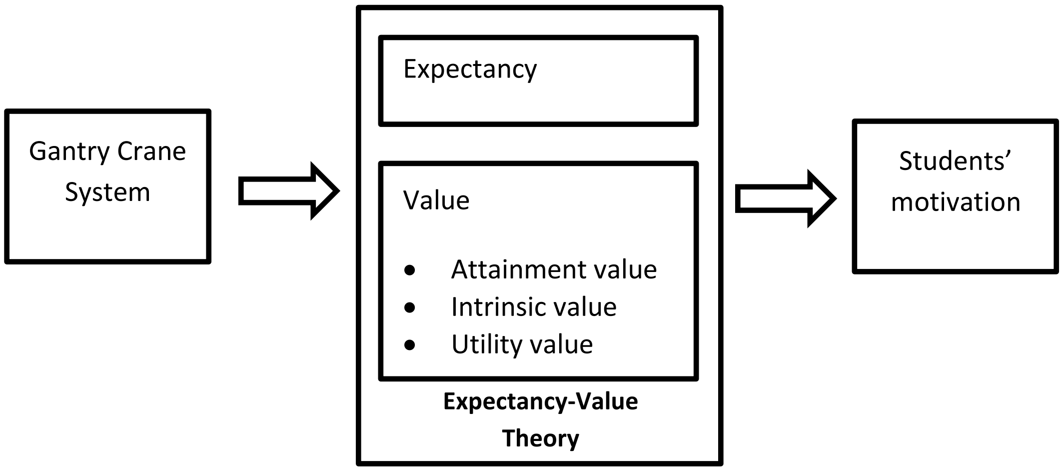

Fig. 1. The framework of implementation Expectancy-Value theory in gantry crane system PjBL

The present study is mainly to describe the PjBL as an approach of learning to achieve the specific ILOs in the System Modeling and Analysis course. The course is taught to third-year students at the School of Electrical Engineering, Universiti Teknologi Malaysia in semester 1 of the 2020/2021 academic session. Previously, the course was conducted using a series of summative assessments such as tests, quizzes, and examinations. Formative assessment occurs only during lectures or discussions. At the end of the course, the students' feedbacks were collected. Many students feel that it is hard to imagine what they have learned in this course and where they will apply it. They believe that the mathematical equations presented in the course are unreal, making it difficult for them to associate what they have learned with the real world. As a result, a group of instructors from this course intended to solve the problem. With reference to several publications related to the PjBL implementation in engineering courses, a PjBL is crafted based on the expectancy-value theory to enhance students' understanding in the System Modeling and Analysis course.

The PjBL is designed by taking into consideration both expectancies from the instructor and the students. In the earlier part of the semester, the students are briefed in 1 hour on the project structure and the aspects of value based expectancy-value theory. The problem created in the PjBL is designed to map to all chapters (a total of 5) under this course syllabus, covering one whole semester of 14 weeks. The details of the PjBL will be explained in the next section. During the task execution, a series of group and individual assessments were performed to evaluate the students' performance. In contrast to the work in Xiaoxiong [12] and Sababha *et al.,* [13], the present study includes a more comprehensive description of the problem design and its corresponding set of tasks and assessments together with an online implementation platform. In addition, the students' reflections were gathered using a set of questionnaires created by Mahasneh and Alwan [3] and Sanger and Ziyatdinova [10]. To create an excitement to the students, a competition is planned at the end of the semester in which the best project outcomes will receive a certificate of appreciation which is inherently interesting to the students.

Many control systems can satisfy the learning objective of the course discussed in this study. However, the gantry crane system (GCS) is chosen in this study due to the characteristic of the system that comprises many mechanical and electrical engineering elements. This may help students to learn from some ~~a~~ multidisciplinary engineering background. In addition, the designed PjBL could also be used not only by electrical background students but also by mechanical background students. Therefore, this work is aimed to help students to understand the meaning of the System Modeling and Analysis course by connecting and relating the situation context, the social and the daily life application through the GCS.

2. Crafting of Gantry Crane System (GCS) Problems

2.1 GCS Intended Learning Outcomes (ILOs) Design

Cranes are machines that are used for transporting payloads or hazardous materials from one place to another. These actions commonly take place in industries such as factories, constructions, marine industries, and harbor loci. Numerous types of cranes are widely used in many industrial sectors, for example: an overhead or bridge crane, a gantry crane, a boom crane, and a rotary (tower) crane. In industries, a fast and accurate positioning of trolley and payload is desirable as this translates into a higher production rate, which directly related to the cost and profit of the companies. Therefore, the modeling, simulation, analysis, and controller design of the crane system are carried out in order to achieve these objectives with the best system performance. The basic GCS model is shown in Figure 2 and the variables are defined in Table 1.

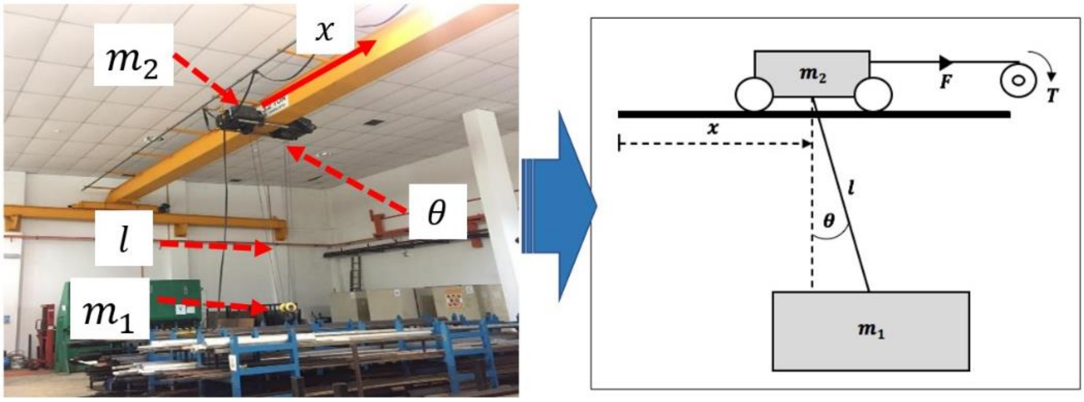

Fig. 2. GCS model

Table 1
List of symbols

m_1	Payload mass	g	Gravity	r	Gear ratio
m_2	Trolley mass	B	Damping coefficient	L	Inductance
l	Cable length	V	Input voltage	i	Armature current
x	Trolley displacement	R	Resistance	T_L	Load torque
θ	Payload swing angle	K_t	Motor torque constant	T_m	Motor torque
T	Torque	K_e	Electric constant	θ_m	Rotor angle
F	Driving force	p	Radius of pulley	J_m	Motor inertia

The GCS project-based learning is divided into five tasks to make sure that the ILOs is achieved at the end of the semester. The students should have a clear understanding of the stated ILO in Table 2 and the tasks given related to the ILOs. The project starts with TASK 1, where the students were required to study the basic principle, the design, and the operation of the GCS, to determine the control objectives, the inputs, and the outputs parameters of the system as well as the problems of crane operation in industries.

The second task is to model the crane system based on the information gathered in TASK 1. In TASK 2, a mathematical equation representing the dynamic model of the GCS for the trolley displacement, x(t), and the payload angle, θ(t) with respect to the voltage input is developed. The model needs to be derived in the transfer function form and the state-space representation. These models will be used in TASK 3 to analyze the dynamic characteristics and determine the stability of the system. This task is based on the basic control theory such as the pole-zero mapping and is achieved by selecting a set of parameters within the given range and specifications.

In TASK 4, the simulation study is performed to evaluate the response of the GCS. The model derived in TASK 2 is developed using a Simulink block diagram. With the parameter used in TASK 3, the output response of the trolley and payload are observed with different payload masses, cable lengths, and swing angles. This task is to expose the students to the actual situation that occurs in the GCS, where the GCS usually carries various payload masses and the variation of cable length for loading, transporting, and unloading operations.

An excessive payload swing is dangerous and could be harmful to humans and their surroundings. Thus it is desirable to reduce the payload swing while keeping a fast crane motion simultaneously. In TASK 5, the controller was designed using a basic Proportional controller to improve the performance obtained in TASK 4. In addition, a filter also needs to be designed to modify the input signal and to remove the critical frequency component so that the speed of the trolley displacement can be improved, and the payload swing can be reduced. The tasks are summarized in Figure 3.

Table 2
ILOs and task mapping for GCS PjBL

ILO No.	Details intended learning outcomes	PjBL task	Chapter
1	The students should have a proper understanding on gantry crane system design, operation principle, and the basic problem background of the crane control system	TASK 1	1, 4
2	The students should be able to state assumptions and derive mathematical models from the first principles, able to derive the input-output model in transfer function and state-space representation	TASK 2	2, 3
3	The students can study the system characteristics from the obtained models using Matlab software, can develop Matlab m-file to identify poles and zeros and their locations, as well as the stability of the system based on the range of the given parameters	TASK 3	4, 5
4	The students can do simulation and stability analysis of crane system. The students should be able to simulate the system model using Matlab Simulink and investigate an appropriate input signal that can control the trolley displacement and payload oscillation	TASK 4	5
5	The students should be able to design filters and controllers to improve the trolley displacement movement and minimize the payload oscillation	TASK 5	5

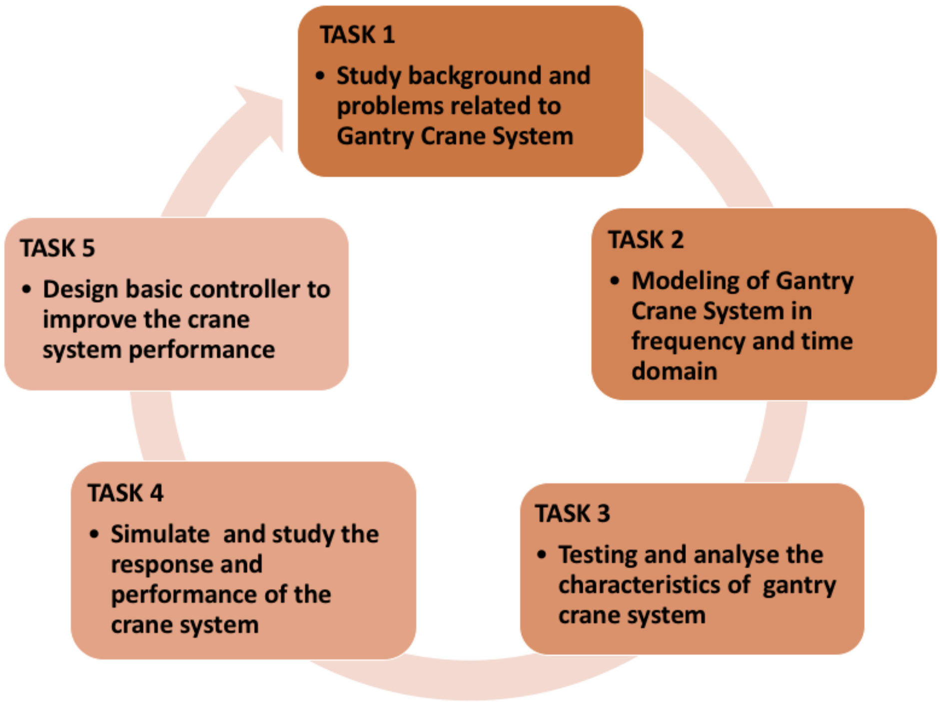

Fig. 3. PjBL tasks

2.2 Teaching and Learning Activities (TLAs)

An excessive payload swing is dangerous and could be harmful to humans and their surroundings. The PjBL was implemented online for 14 weeks, from week 2 to week 15 throughout semester 1 of the 2020/2021 academic session. The students were grouped into 3 to 4 members. During the implementation period, several activities and assessments were conducted including active learning (AL).

Initially, under the instructor's supervision, a Jigsaw was conducted for TASK 1 from weeks 2 to 4 to allow students to discuss and share their ideas among the groups' experts (EG) and team members (Home Group, HG). During this activity session, the lecturer facilitates and guides the students' ideas and opinions, encourages critical thinking in solving the project given. This activity was performed via a forum in the E-Learning platform. To evaluate the students' participation, numbers of replied discussions were recorded for each group, and students' reflections were also collected.

From week 5 onwards, a group discussion continued within their HG via the forum in the e-learning or any suitable conference platform agreed upon within the team. At the end of week 8, all groups submitted their progress reports that consists of TASK 1 and TASK 2 activities. Starting from week 9, all groups conducted a simulation study using Matlab software; where TASK 3 was performed using an m-file coding, while TASK 4 and TASK 5 were simulated for the complete system using Simulink block diagram from week 12 to week 15.

For the individual assessment, a hands-on Matlab simulation session was conducted. Finally, all groups were required to submit a group report for the assessment. The final reflection was collected from all students for future improvement. Table 3 shows the constructive implementation for this project.

Table 3
Constructive implementation for PjBL

Week	ILO no.	TASK no.	TLA	Assessment tasks
2-4	1	1	Jigsaw	• Expert group discussion in e-Learning forum • Home group discussion in e-Learning forum *In this task, students must seek additional information from a variety of sources in order to connect the problems presented with the course content
5-8	2	2	Group discussion	• Individual discussion in e-Learning forum • Group progress report *from Task 2 onwards, students are expected to have a strong fundamental understanding of the project and continue working on it in accordance with the course chapter
9-11	3	3	Group work	• Peer evaluation • MATLAB via m.file coding • Group discussion in e-Learning forum
12-14	4	4	Group work	• Simulation design (MATLAB) using Simulink • Group discussion in e-Learning forum
15	5	5	Individual and group work	• Individual hands-on simulation demonstration • Group report • Individual reflection

3. Findings and Discussion

The effectiveness of the PjBL was measured based on reflection and feedback. Two questions were given to the students via E-learning platform. The majority of students (250 respondents) have provided their comments and suggestions. The feedbacks are grouped into six themes using thematic analysis as tabulated in Table 4. In response to the first question, it is discovered that the project's attainment value was achieved when the majority of students agreed that the PjBL was able to enhance their understanding in modeling and analysis by exposing them to a practical problem. For the utility value, since the PjBL is a group project, the interaction among group members and task distribution are expected to have a favorable impact on their motivation to improve their generic skills. With a crane system that combines interdisciplinary engineering background, students realized that the project had prepared them for their future industrial employment. This demonstrates how the utility value was attained. The intrinsic values can be seen in the competition organized by the instructor, in which the students participated actively in the designed activities and were excited to receive the certificate of award [4].

In response to the second question, the PjBL designer and instructor may find these suggestions useful for the future as shown in Table 5.

Table 4
Students' feedback

Items	Samples of student's feedback	
What are the advantages of doing PjBL in this course?	Strong understanding on the application of system modeling towards industries	Dealing with a practical problem is a huge advantage as it prepares for industrial work
	Learn new things, enhance knowledge, teamwork, and communication skills	It helps me to understand how the modeling to control system works in real life
	Learn more about control systems and using simulation software like MATLAB and Simulink function	Able to gain practical experience in the design of control systems from basic

Table 5
Students' suggestion

Items	Samples of student's suggestion	
Give your suggestion/opinion on how to improve the PjBL implementation in the future	Relate the industrial concerns such as cost and material in the case study	I hope that we can build a small crane that can simulate what we program into the real world
	Give at least 2 different projects (individual & group) where the pattern of the task is almost the same. When they work in a group, they can give the best idea because they have experience for individual task	Students need experience on how to handle the MATLAB earlier in the Basic Control lab, thus, a student can explore more on this project.
	It would be more interesting if we can combine with other courses for a more complex system	It would help a lot if this project required the student to make a prototype

At the start of the project, the students and the instructors believed that the students Matlab programming skills were sufficient for the PjBL. The expectancy, on the other hand, was high. During the project's execution, the students realized that having a good knowledge of Matlab programming software helped them in doing the PjBL faster because they did not have to spend much time in debugging the code. However, more industry-related content such as the material and cost, prototype, and the complexity of the system should be incorporated in future PjBL implementations. This is so because the students have shown a substantial amount of interest and enjoyment. This also indicates that the utility value has been achieved [11]. One interesting suggestion that the designer could consider in the future is to create a system prototype as part of the PjBL, where students can transform their knowledge into a tangible form. However, not all suggestions are appropriate. The PjBL should be designed based on the course learning outcomes that have been established earlier.

4. Conclusion

The project-based learning has several activities that include individual tasks, teamwork, peer evaluation, and software development. As a result, it enriched the students' development in both hard and soft skills. Moreover, while working on the project, students implicitly also learn the course content and gain a deeper understanding on what they are doing. They can relate the theoretical concept in the classroom to real-world problems.

There are significant findings towards the expectancy-value model that has been used. It shows how the students have been motivated to complete the project given. However, the survey tools can be improved to investigate detailed findings in the future such as performing repeated surveys to see whether the motivation of the students may change or not during the project execution.

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