MULTI-DISCIPLINARY DESIGN-BUILD PBL AS AN INTRODUCTION TO ENGINEERING

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ABSTRACT

A project based learning (PBL) project is designed as an introduction to engineering, requiring the student to design and build a computer-controlled tower crane at Shantou University (STU). This project is developed as a result of a recent STU-MIT collaboration. The project is designed in accordance with the CDIO initiative. The students in teams are expected to divide themselves into five different disciplinary subgroups, namely, co munication, computer programming, electronic engineering, mechanical engineering and civ l/structural engineering. Through the students were freshmen just entering the university, t y performed satisfactorily.

The project was proposed by STU, alpha-tested at MIT and beta-tested with a group of students at STU before actually implemented with the full cohort of students at STU. In the beta-test, the group of students approached the solutions in an ad hoc fashion together hey did not realize the multi-disciplinary nature of the project and thus did not make due decompositions and coordination to tackle the problems. Therefore, in the actual implementation of the project, targeted support was given to the students. Instead of directly asking the students to divide themselves into disciplinary subgroups, we helped the students to model the operation process of the crane. The process modelling helped the students to understand the different modules (relevant to different disciplines) and the input/output of each module. Thus, they could divide themselves into subgroups according to the modelling modules and oordinate according to the input/output requirements.

The results of the implementation show that the multi-disciplinary project is a good introduction to engineering. The design and build context helped the students to achieve the desired CDIO learning outcomes. The process modelling helped the students to decompose tasks, focus on specific problems and manage the project with confiden e.

KEYWORDS

Introduction to engineering, multi-discipline, PBL, design-build exercise, project management

INTRODUCTION

Project based learning (PBL) is an important means to integrate the CDIO skills with disciplinary knowledge. Design-build projects provide excellent experiences for students to appreciate engineering practice. We have developed a freshman-level, multi-disciplinary project-based learning experience for a cohort of 375 students from 5 engineering programs.

In 2009, MIT and Shantou University (STU) worked together to support engineering education at STU. Part of the cooperation was to benchmark the learning projects done at MIT, STU and other universities known for their advanced developmen of PBL. This information could be used to further refine the project based approaches at STU. A standard template was developed for the benchmarking and description of PBL experiences, so that a complete and usable description of project-based learning resources could be made available to all instructors at MIT and STU.

Six projects, 2 proposed by MIT and 4 proposed by STU, were designed and alpha-tested at MIT and then beta-tested at STU, to prepare for implementation during the school year. Three MIT staff came to STU for a week of workshops with faculty and selected grou tudents. The 6 projects, together with 7 additional proposed projects were then further refined and implemented at STU in the Fall semester 2009. These would then be used and summarized as templates of project-based learning in line with the CDIO initiative at STU.

Among the 6 projects, conceiving, designing, implementing, and operating a tower crane was proposed by STU as a freshman introduction to engineering project. Students working in teams were required to design and build a computer-operated, motor-powered tower crane with supplied motors, transistors, bearing, pulleys, and galvanized steel wires. Each team then competed against other teams in the end of the semester.

For the crane project, the multi-disciplinary nature, limited knowledge and experience of the students and the large numbers of students pose a vari ty of challenges to the organization of the project. In fact, such a project had been conceived for two years without being actually implemented because it is so challenging that we were afraid that we could not handle the problems might be encountered in the course of the pro ect. The STU-MIT collaboration provided us an excellent chance to conduct the two rounds of tests before actually put the project into practise. From the beta-test, in which a group of students did the project on a compressed timeline, we learned that the critical problem preventing the students from arriving at a good design was that they did not realize the complexity of the project and hence did not go through a well-ordered planning process. Therefore, in the actual implementation, we helped the students to use modelling methods to delineate tasks of different disciplines, and t en pinpoint and overcome major difficulties of individual disciplines separately with confidence. The project template developed by MIT provides us an excellent tool to enhance our project design and correlate the project implementation with the CDIO lear ing outcomes.

PROJECT DESIGN

The crane project is the core part of the course “Introduction to Engineering Design”. The goals of the course include providing the students basic exp ence with hands-on implementation, project management, teamwork and multi-disciplinary team collaboration as well as disciplinary knowledge. The course is delivered to all freshmen of the Colle e of Engineering in their first semester at STU. It was thus expected that a common project include basic disciplinary content from all five STU engineering programs: mechatronics, civil engineering, electric and electronic engineering, communication engineering and computer science. To that end, each project team is required to design and build a computer-controlled tower crane with given parts and materials. At the end of the semester, each team is required to operate the crane, and a competition is held to see which team finishes a set of hoisting operations in the shortest time. At the competition site, a set of hoisting orders are only given to one team member. He/she must communicate this set of orders without using any vocal visual means to the member operating the computer, which controlled the overall hoisting process. The students are not allowed to touch any part of the mechanical setup, including the crane and weights. This project design includes components from all five disciplines: communication (hoisting instruction transmission), computer programming (computer interface and digital output programming), electronics (circuits translating digital signals and power input into motor drive output), mechanical engineering (mechanism and transmission design) and structural eng neering (strength and stability design of the tower). Each team contains team members from every discipline, using every student to have this experience in a multi-disciplinary teamwork context.

While specifying the project requirements and constraints we tried to give maximum innovative leeway but keep the overall level of complexity manageable. No electronic means was provided for communication. Instead, direct hand-to-hand contact was used as the communication medium, so that the students could focus on the balance between efficiency and reliability of communication rather than the underlying technology. Visual Basic is used as the programming platform. A commercial data acquisition card, Computer Measurements' USB-1208FS, is used for outputting digital signals. The DAQ card has accompanying VB libraries removing the need for hardware configurations and programming, so the programming students can limit their attention to designing the interface and pulse-width-modulated output (PWM). The electronic circuit is expected to convert the DC power supply from a battery and the modulated digital signals from the DAQ card into motor driving and contr lling signals. No IC drivers are allowed -- the students are expected to use transistors and resistors to build H bridges to realize the driving circuit. The mechanical design must fulfil the specified hoisting operations: transmissions must be designed and built for motors to hoist the weight and control radial and angular motion. The tower structures are constructed using 1.6mm galvanize eel wires. The structural group would have to ensure the overall stability, the strength and stiffness of the structur s.

Each team receives 3 DC motors, 10 PNP transistors, 20 NPN transistors, 1 thrust bearing, 20 ball bearings, 15 pulleys, two sets of worm and worm gears, 1kg Φ1.6mm galvanized steel wires, some resistors, a veroboard and some other mate ls and hand tools.

A tower crane is required to fulfil the following spec ations:

- Maximum lifting loading 1kg;
- Maximum lifting height 500mm;
- Working radius within 150mm-350mm;
- All lifting operation being operated at a computer interface;
- The crane must support itself in the full course of the operation process without any external anchorage;
- During operation, a set of lifting orders are given to team member, who must communicate the orders to another member using only hand-to-hand contact.

PROJECT IMPLEMENTATION

In the 2009/2010 Fall semester, a total of 361 students were divided into 4 classes, nearly 100 students a class. The students were grouped into 9-10 students per team. Each team was required to design, build and operate a tower crane at the end of the semester. The students attend a two hour class every other week, making a total of 16 contact hours. About half of the contact hours were used for the students to present and discuss their designs -- the students needed to learn, design and build in their own time. The CDIO Center of the College is open to all students.

It is overwhelming for the students just coming into t e university to face such a complex project. During the beta-test, a group of four first- and second-year students, similar to our intended audience, experienced the design and build process. In four full days, they designed and built a crane that could be operated by a computer. However, the crane could not lift the targeted weight of 2kg, with insufficient stability and stiffness. Also, their conduct of the project revealed that the group did not fully appreciate the multi-disciplinary nature of the project and hence did not make due coordination to deal with the complexity, nor did they have clear design ideas.

While facing the project assignment, the first common student reaction is, “We have not yet learned any relevant technical knowledge. Hence we don’t know what to do”. Consequently, they were hardly able to organize disciplinary subgrou and make due plans and designs. Taking lessons from the beta-test, we helped the students to clearly understand the roblem through modelling the process as illustrated in Figure 1:

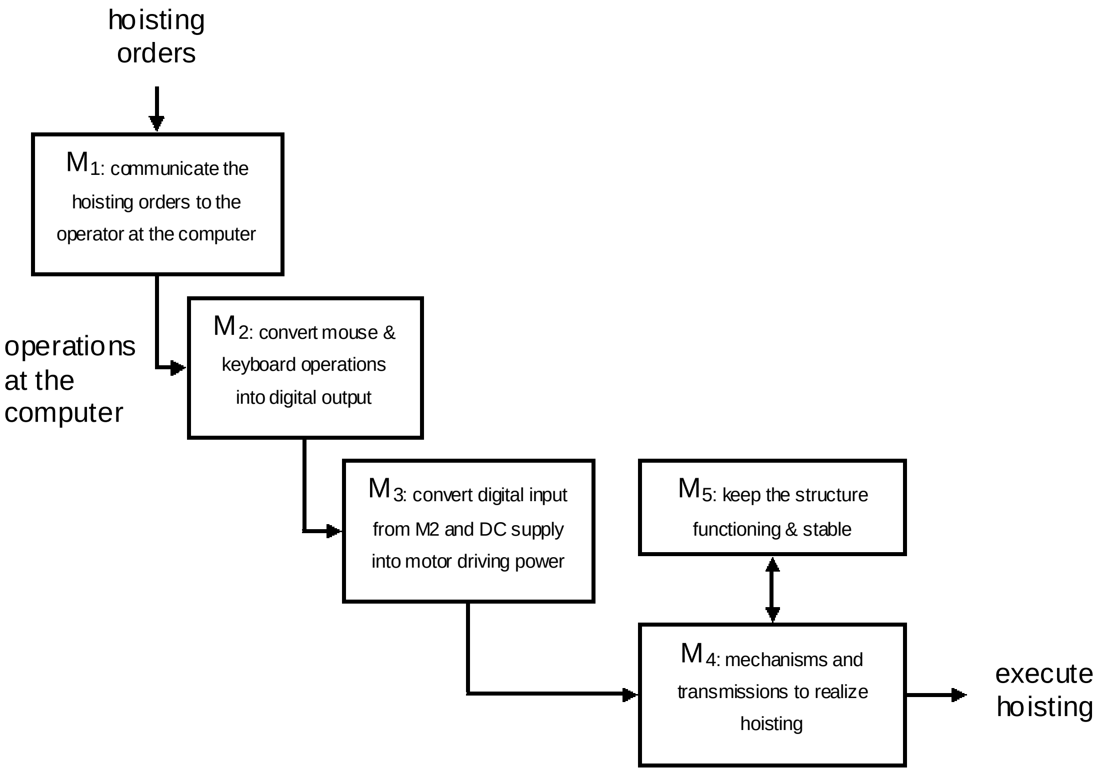

Figure 1. Process modelling of the crane operation

Module M_1 requires the student holding the hoisting orders to communicate the orders to another student with hand to hand connections only; they must not use any sound or visual means. This forces them to workout a set of agreements on coding nd communication protocol. A team's performance is measured as the overall time from receiving the hoisting orders to correctly fulfilling the hoisting tasks. Therefore, time used for communic ion must be kept to a minimum. By doing so, the students would understand cl rly the tradeoffs between efficiency and reliability. This also leads them to understand th basic components and their functions of a communication system.

Module M_2 requires to program a computer interface that converts mouse clicks on the interface into modulated digital signals from the DAQ digital pi s. The Visual BASIC programming environment is provided. The DAQ card supplies a unive l library for manipulating the input/out operations. Therefore, the programming task is fairly sim le and easy to learn, and achieving control via a computer gives the students a sense of accomplishme t and stimulates their interest in learning. They need to program for s hing, reversing and acceleration/deceleration, for which they would need to understand the concept of PWM. Aesthetic and user-friendly interface design is also a part of the consid rations the students should pay attention to.

Module M_3 refers to an electronic driving circuit converting modulated digital signals input from the DAQ card and the DC power supply from the battery into motor driving c rents. It is expected to be composed of 6 H bridges using given tra sistors and resistors. Once the students understand the fundamental principles, it is fairly simple for them to work out the seemingly complex circuit. The module provides them with good opportunities to practice soldering and debugging. There are also a lot of overheating and burning cases due to various reasons. It provides a good starting point for the students to become familiar with electronics within a practical application context.

Modules M_4 and M_5 produce the physical working mechanism together. M_4 determines working mechanisms, the power transmissions and the overall dimensions. M_5 determines the skeletal structures ensuring the overall stability, the strength and the stiffness of the crane. For M_4, vertical lifting, radial moving and tower rotation need to be realized through the three motors. Two major issues need to be conceived and designed, one being the mech isms fulfilling the designated movement, the other being the ways and installations of the power transmissions. For the first issue, reference can be made to tower cranes seen in the real world. T independence axiom of the axiomatic design theory was i roduced to help the student make uncoupled designs. The power transmission problem is t e most difficult one. Due to limited knowledge, limited machining and fabrication tools and lack of theoretic understanding, it is very difficult for the students to come out with robustly designed, well-installed and reliably working transmissions. Interestingly, radial movements are the difficult to realize reliably.

The students have learned Newton's mechanics of force. They understand the concept of equilibrium. With enough experimentation they should be able to fabricate the structure using the assigned steel wires. Unfortunately, reality did not support this assumption. Most groups did not do scientific experimentations to find the best structural configurations. Instead, they tried to avoid using the given steel wires to support the crane . This experience demonstrated that more guidance is needed to lead the students to identify engineering solutions.

By modelling the crane operation process, the students were able to delineate the functions of different modules. From the functions of the modules disciplinary subgroups could be formed. By defining the functions and input/output requirements, h subgroup narrowed down its concentrations. Each subgroup needed only to work out lutions for a specific set of requirements, which helped minimize the students' panic. Multi-disciplinary group coordination and planning became tangible to the students.

Further modelling should have been carried out for individual subgroups to approach the solutions with a systematic way. However, due to minimal staff levels and limited contact hours such modelling was not commonly practised in the subgroups.

Information for students about the project was given with project social background, crane operation process modelling, background of relevant individual disciplines and quick references to the fundamentals with regard to the project.

As a group project, the students needed to follow project management routines to do the meeting, planning, presentation and report-writing. Because the students were in the process of learning and exploring, they had problems with decomposing the subtasks and making good progress plans.

Figures 2 – 9 show some of the designs and their products.

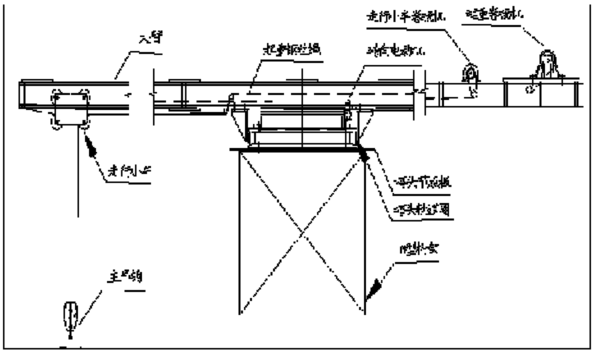

Figure 2. Design of a team

Figure 3a. Hoisting operation in process

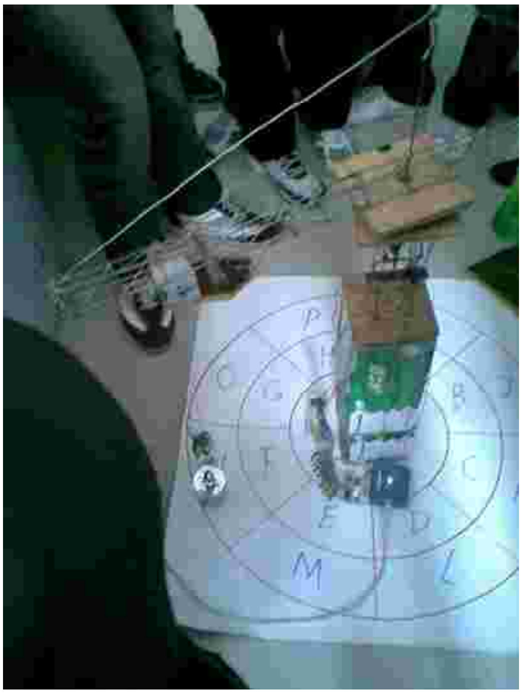

Figure 3b. Hoisting operation in process

Figure 4. Connecting to the data acquisition card

Figure 5. Hoisting order transmission

Figure 6. Group discussion

Figure 7. The circuit board

Figure 8. Rotational movement transmission

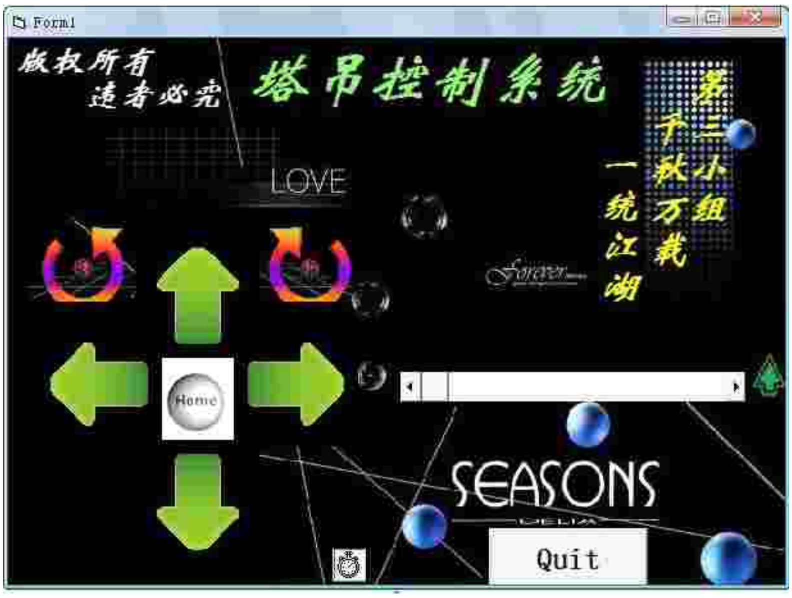

Figure 9. The computer user interface of a team

LEARNING OUTCOMES WITH REGARD TO THE CDIO SYLLABUS

Based on the project design and the actual conduct of the pilot tests and practical implementation, the learning outcomes with regard to the CDIO syllabus are listed in Table 1. The remarks on the right explains the "I", "T", "U" measures to ensure the specific learning outcome is fulfilled.

Table 1
Learning outcomes and the corresponding realization me sures

CDIO learning outcome 1. Technical knowledge and reasoning	Remarks
Understand basic ideas of mechanical transmissions	I, U, Realization of transmissions for the three dimensional movements.
A first exposure to mechanisms	U, Realization of the designated crane functions.
Reflect on reliability and robustness	I, explain during student consultation
Equilibrium calculations	I, U, Overall stability
Structural stability the resist to buckling	I, U, Design and construction of the tower and the beam
Transistor switching circuit, H bridge	I, U, realization of the motor driving circuit
Pulse width modulation	I, U, motor acceleration/deceleration control
A first experience with Visual Basic programming	U, programming of the user interface and the modulated digital output
Number system	I, U, Choice of number systems in hoisting

	order communication
Communication: medium, efficiency & reliability, bandwidth, protoal	U, fulfilment of the hoisting order communication
2. Personal and professional skills and attributes	
2.1.2 Modelling	I, U, Process modelling
2.1.3 Estimation and Qualitative analysis	U, determination of the dimensions of the crane parts
2.1.5 Solution and Recommendation	U, All problems encountered in the project
2.2.2 Survey of Print and Electronic Literature	U, This is the major way for the students getting helps
2.2.3 Experimental Inquiry	U, Can be systematically practised in determining the supporting structures. Trial-and-error for other parts.
2.3.1 Thinking Holistically	U
2.3.3 Prioritization and Focus	U
2.3.4 Trade-offs, Judgement and Balance in Resolution	U
2.4.2 Perseverance and Flexibility	U
2.4.3 Creative thinking	U
2.4.5 Awareness of One's Personal Knowledge, Skills and Attitudes	U, Assessed from personal reflections
2.4.6 Curiosity and Lifelong Learning 2.4.7 Time and Resource Management	U U, Planning and time schedule are required
2.5.1 Professional Ethics, Integrity Responsibility & Accountability	U, Practised in the whole process. Partly assessed from personal reflections
3.1.1 Forming Effective teams	U
3.1.2 Team Operation	U, Meetings, minutes taking, brainstorming, etc are required to be recorded. Assessments given.
3.1.4 Leadership	U, Bonus marks given to team leaders according to team performance
3.1.5 Technical Teaming	U, Technical subgroups are formed to work together.
3.2.2 Communication Structure	U, All teams are required to do oral presentations and answer questions in front of the whole class.
3.2.3 Written Communication	U, Formal reports are required according to given format.
3.2.4 Electronic/Multimedia Communication	U, All reports are electronic. Electronic hand-in system used. PowerPoint presentations are required. CAD drawings are recommended.
3.2.5 Graphical Communication	U, Practised in discussions, presentations and reports.
3.2.6 Oral Presentation and Inter-Personal Communications	U, Practised in discussions. Oral presentations are assessed.
3.3.1 English	U, An abstract in English is required.
4.4.1 The Historical and Cultural Context	I
4.3.2 Defining Function, Concept and	I, U

Architecture	
4.3.3 Modelling of System and Ensuring Goals Can Be Met	I, U
4.3.4 Development Project Management	I, U, Project planning required. Resource restraints imposed. Documentations required.
4.4.1 The Design Process	U
4.4.2 The Design Process Phasing and Approaches	U
4.4.3 Utilization of Knowledge in Design	I, U
4.4.4 Disciplinary Design	U
4.4.5 Multidisciplinary Design	U
4.5.1 Designing the Implementation Process	U
4.5.2 Hardware Manufacturing Process	U
4.5.3 Software Implementation Process 4.5.4 Hardware Software Integration	U U
4.5.5 Test, Verification, Validation, and certification	U, Not formal verification, validation and certification not touched.
4.6.1 Designing the Optimizing Operation	U, Observations and discussions of the design and test process, improvement suggestions are required in report.
4.6.5 Disposal and Life-End Issues	U, Disposal & environmental problems need to be considered.

STUDENT REFLECTIONS

Below we summarize some of the student feedback. These are the most important reasons for introducing PBL into our curriculum. It appeared that a complex, multi-disciplinary project would indeed give students a different learning and enhance heir thinking and problem solving skills.

What The Students Feel They Have Learned

I learned how to simplify a complex task. I learned how to fulfil my own job within a group working on a complex task. I understand better the importance of design. … leant how to learn better.

I learned to think from objectives before start working. I feel that my thinking skill is improved.

We learned how to approach our teachers and elders independently.

I learned how to effectively use information in the library. I learned how to divide tasks but at the same time collaborate with my team mates. I have better hands on skills and can think more independently. The project broadened my thinking on how to discover a p oblem and find ways to solve it. This indeed makes me exciting.

Change the ways of Learning

This is an interesting process. You thought it would b ok just learn it. Later on you found it's not as simple as that. Then you wanted to go back to learn it again but you were short of time. So, you just went directly to the point. This way I improved my rapid learning skill.

It is a gradual process, from outside to inside, from mple to complex, from general to specific, step by step until touching the core.

We used septenary system. After many times drilling I found myself skilful converting between septenary and decimal numbers. At the same time, I und stand much deeper of the number systems.

Apparently, while transmitting a piece of data, using octal system would need less numbers of signs, ie. higher number systems yield higher efficiency. But they would also need more complex signs to express (more prone to errors).

In the early stage of design, I was responsible for calculating the length of the beam and the lifted weight. I established the equilibrium equations using my mechanical knowledge. It was not difficult. …This was different from doing exercises in a textbook. I need to determine the initial parameters by myself. I spent five hours to calculate ny combinations of parameters and chose the best out of them.

Change of Attitude

In difficult situations, I would need to question and lect "why" and "how". It urges me think thoughtfully with different angles. This stimulate our innovative po entials.

In the course of the project, I experienced all kinds feelings, depressed, obstinate, arrogant, fretting and wanted to give up. Looking back upon completing the work I understand myself better. It encourages me to consummate myself.

I learned that … we must assume a good attitude toward a task.

While facing a problem, the most important is to figur out the ways to solve it and work on it step by step. Gradually you will find the answer.

A Different Learning Experience

In the end, we completed the initially seemed impossib e task.

When our painstaking product passed the test and was a eciated, we understand more about our competency. We felt that a team is powerful, so powerful that it can solve hard problems.

We put the end product of our full semester hard working on that piece of paper, looked at the weight being lifted smoothly, everybody of us was excited.

In the evening we passed the test we went to the East e to celebrate, celebrate the joy of success after spending great efforts together.

This is a process. In this process we experienced the oys of successes and the depression of failures. In the end we fulfilled our task and learned something.

I got to know a group of buddies, learned some knowledge and morals, experienced the joy and happiness of the process.

DISCUSSIONS AND CONCLUSIONS

In the beta-test, the group of students approached the solutions in an ad hoc fashion. In the end, they missed important issues such as the overall stability of the crane. This alerted us of the importance of guiding the students to understand the multi-disciplinary nature of the project and identify functional decompositions to simplify the problem. In the first trial of the project, the students panicked because of the complexity. While there may be some benefit to permitting an unstructured, chaotic period before the students finally find a solution, it poses difficulties for the overall project timeline. When they have a poor overall grasp of the project, it is hard for them to decompose the tasks and make working plans. It is a challenge to balance between maintaining the complexity of the project and giving the students enough guidance. Our implementation shows that modelling is a good way of doing so.

The project offers the students a learning experience t t nurtures social learning and stimulates innovations. It serves as an introduction to engineeri g and a first instance of design-build experience. Furthermore, it provides the students an early opportunity to appreciate the multi-disciplinary nature of product development. The design and build context helped the students to achieve the desired CDIO learning outcomes. The process modelling helped the students to decompose tasks, focus on specific problems and manage the project h confidence.

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