CDIO curriculum for mechanical engineering undergraduate course

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ABSTRACT

A unique approach to the use of the Project Based Learning to transform the curriculum into CDIO curriculum is achieved through the use of carefully selected projects for the Engineering Design modules (which are Project Based by nature) and use these modules as platforms to encourage practical engagement in other concurrently offered modules which are traditionally viewed as theory based modules. Simple as it may look, this approach requires a high level of coordination on the part of the lecturers delivering the concerned modules to ensure that the required objectives are effectively achieved. This paper reports on the use of the "Engineering Design and Professional Skills" module, offered at the second semester of the second year of a four-year Mechanical Engineering course, in conjunction with a theory based module namely: "Flows with Friction, Drag & Lift" offered at the same semester, to create a CDIO environment without introducing any major changes to the syllabus of the theory based modules or to their assessment scheme. The students were divided into groups and each group was assigned the task of conceiving, designing, implementing and operating a fluid related project. In brief, the "Flows with Friction, Drag & Lift" provided the theoretical backbone for the project, while the "Engineering Design and Professional Skills" module provided the platform through which the project management and team work skills are developed and the progress of the projects is monitored. The students exhibited a high level of engagement and motivation while gaining a better understanding of the real fluids related theory.

Keywords: *CDIO, Project Based Learning, Drag and Lift, Engineering Design.*

INTRODUCTION

In contemporary undergraduate engineering education, there is a seemingly irreconcilable tension between two growing needs. On one hand, there is the ever increasing body of technical knowledge that it is felt that graduating students must command. On the other hand, there is a growing recognition that young engineers must possess a wide array of personal, interpersonal, and system building knowledge and skills that will allow them to function in real engineering teams and to produce real products and systems (Crawley, 2001).

In order to resolve this conflict, innovative solutions, that do not overload the students and lectures, are required. The Conceive-Design-Implement-Operate (CDIO) initiative is one of the widely accepted solutions to achieve these objectives (Crawley et al, 2007). CDIO initiative advocates an engineering education that stresses the fundamentals, set in the context of the product-system lifecycle, which can be thought of having four metaphases: Conceiving-Designing, Operating- Implementing (Bankel et al, 2005). This is done normally using educational approaches that are active, hands on and project-based in order to achieve integrated learning, where acquiring of disciplinary knowledge and CDIO skills takes place simultaneously. The philosophy of the CDIO initiative is outlined by the 12 standards and the syllabus it adopts. These standards and syllabus are listed in Figure 1 and Table 1 respectively.

Gustafsson et al (2009) presented a study of four first-year engineering introductory courses, from different universities that participate in the CDIO Program. The courses were discussed with an emphasis on the student projects in them and it was shown that these introductory courses are an ideal testing ground for the CDIO approach, where new ideas can be tried, developed and assessed to support the learning of CDIO skills. Similar approach was reported by Al-Atabi (2009) where he used an introductory design course as centrepiece to integrate the curricula of a first year mechanical engineering undergraduate course.

A unique approach to the use of the Project Based Learning to develop CDIO skills can be achieved through the use of carefully selected projects for the Engineering Design modules (which are Project Based by nature) and use these modules as platforms to encourage practical engagement in other concurrently offered modules which are traditionally viewed as theory based modules.

Simple as it may look, this approach requires a high level of coordination on the part of the lecturers delivering the concerned modules to ensure that the required objectives are effectively achieved. This paper reports on the use of the "Engineering Design and Professional Skills" module, offered at the second semester of the second year of a four-year Mechanical Engineering course, in conjunction with a theory based module namely: "Flows with Friction, Drag & Lift" offered at the same semester, to provide an integrated Project Based Environment that addresses the CDIO standards and syllabus without introducing any major changes to the syllabus of the theory based modules or to their assessment scheme. A class of thirty five students was divided into five groups and each group was assigned the task of conceiving, designing, implementing and operating a project that is related the "Flows with Friction, Drag & Lift" module. The "Engineering Design and Professional Skills" module provided the platform through which the project management and team work skills are developed and the progress of the projects is monitored, while "Flows with Friction, Drag & Lift" provided the theoretical backbone for the project. Throughout the course, the students exhibited a high level of engagement and motivation while gaining a better understanding of the real fluids related theory.

MODULES DELIVERY

The two modules selected for this project are "Design & Professional Skills" and "Flows with Friction, Drag and Lift" which is an advanced fluid mechanics course. These two modules run simultaneously for 11 weeks during the second semester of the second year of a four year mechanical engineering undergraduate programme. The students need to attend 4 hours of classes, labs and tutorials for each module every week. The aim was to introduce as little modification to the existing mode of delivery and assessment as possible while ensuring the CDIO standards and Syllabus are addressed.

The "Design & Professional Skills" module is assessed continuously through the coursework. The learning outcomes of the module are listed below.

- Present work to a high standard, both orally and in writing.
- Work effectively within a team.
- Perform information gathering and research effectively.
- Appreciate the strategic management, legal, social and ethical issues related to development of new products.
- Assess risk, health & safety, and environmental issues with a strong emphasis on sustainability related to a design or manufacturing project.
- Demonstrate a working knowledge of the essential elements of project management and be able to produce a project plan for a project of moderate complexity.
- Design and build a product or a system of moderate complexity.

On the other hand, "Flows with Friction, Drag and Lift" is assessed via a coursework component (40%) and a final exam (60%). The learning outcomes for this module are listed below

- Understand the phenomena involved in the development of boundary layers in flow next to a flat plate and separation of flow around shaped bodies, including the role of turbulence
- Calculate the friction and form drag on bodies immersed in flow, including the drag on flat plate with transition layer
- Understand and perform design calculations for the basic lifting surfaces

- Understand the physics of lift and perform the basic calculations for lifting bodies including the use of polar diagrams for the flight cases
- Perform experimental assessment of frictional effects in flow including the measurement of velocity profiles

These two modules are delivered and assessed jointly and the 40% coursework component of the assessment of "Flows with Friction, Drag and Lift" is now assigned to the group project offered at the "Engineering Design and Professional Skills".

PROJECTS OFFERED

In order to achieve the objectives of creating a CDIO curriculum, the following projects were offered

1. Conceive, Design, Implement & Operate a Small Wind Turbine using a Standard Airfoil
2. Conceive, Design, Implement & Operate a Small Wind Turbine using a New Airfoil Design
3. Conceive, Design, Implement & Operate a Small Wind Turbine using Blade Fitted with Wing Tip Sails
4. Conceive, Design, Implement & Operate a Small Wind Turbine using a the Magnus Effect
5. Conceive, Design, Implement & Operate Models of the Malaysian Traditional Kites

A sample hand out for these projects is given in Figure 2. Table 2 shows how different items of the CDIO syllabus are linked to the correspondent learning outcomes developed by the two modules considered in this study. It is clear that the learning outcomes of "Flows with Friction, Drag and Lift" are well linked to the disciplinary aspects of the syllabus while CDIO skills part spreads nicely along the learning outcomes of the "Design & Professional Skills" module. It is important to notice here that the integrated delivery of these two modules transformed the curriculum into one that lives up to the CDIO standards (as outlined in Figure 1).

RESULTS AND DISCUSSION

The experiment of integrating the delivery of existing modules to achieve CDIO objective was very successful. All the groups managed to concur the technical and non technical difficulties and complete their respective projects on time. In general, students performed very well in both modules (including the final exam component of the "Flows with Friction, Drag and Lift"). This indicates that the research and hands on work they performed to complete their project successfully helped them acquire a deeper understanding of the theoretical principles and this is the whole idea behind the CDIO. Using this integrated mode of delivery, most of the CDIO standards were addressed. The level of students' enthusiasm, engagement and motivation was very high throughout the semester. Figure 3 shows samples of the students' projects.

CONCLUSIONS

In order to achieve CDIO standards and develop CDIO curriculum using existing academic modules, a theory based module "Flows with Friction, Drag and Lift" was offered in an integrated manner with a project based module "Engineering Design and Professional Skills". The integration was achieved through the provision of carefully selected design projects that address the requirements of both modules in a balanced manner. The experiment was a great success as the students performed very well in both modules, which serve as an indication of the achievement of the learning outcomes. The students exhibited a high level of engagement, motivation and commitment throughout the semester.

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THE CDIO STANDARDS

Standard 1 — CDIO as Context*

Adoption of the principle that product and system lifecycle development and deployment — Conceiving, Designing, Implementing, and Operating — are the context for engineering education

Standard 2 — CDIO Syllabus Outcomes*

Specific, detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders

Standard 3 — Integrated Curriculum*

A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills

Standard 4 — Introduction to Engineering*

An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills

Standard 5 — Design-Build Experiences*

A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level

Standard 6 — CDIO Workspaces

Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning

Standard 7 — Integrated Learning Experiences*

Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills

Standard 8 — Active Learning

Teaching and learning based on active experiential learning methods

Standard 9 — Enhancement of Faculty CDIO Skills*

Actions that enhance faculty competence in personal, interpersonal, and product and system building skills

Standard 10 — Enhancement of Faculty Teaching Skills

Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning

Standard 11 — CDIO Skills Assessment*

Assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge

Standard 12 — CDIO Program Evaluation

A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement

***** Required

Figure 1: The CDIO standards.

Table 1: Condensed CDIO Syllabus, showing three levels of content detail (Crawley, 2001).

1	**TECHNICAL KNOWLEDGE AND REASONING**
1.1	KNOWLEDGE OF UNDERLYING SCIENCES
1.2	CORE ENGINEERING FUNDAMENTAL KNOWLEDGE
1.3	ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE
2	**PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES**
2.1	ENGINEERING REASONING AND PROBLEM SOLVING
2.1.1	Problem Identification and Formulation
2.1.2	Modeling
2.1.3	Estimation and Qualitative Analysis
2.1.4	Analysis With Uncertainty
2.1.5	Solution and Recommendation
2.2	EXPERIMENTATION AND KNOWLEDGE DISCOVERY
2.2.1	Hypothesis Formulation
2.2.2	Survey of Print and Electronic Literature
2.2.3	Experimental Inquiry
2.2.4	Hypothesis Test and Defense
2.3	SYSTEM THINKING
2.3.1	Thinking Holistically
2.3.2	Emergence and Interactions in Systems
2.3.3	Prioritization and Focus
2.3.4	Trade-offs, Judgment and Balance in Resolution
2.4	PERSONAL SKILLS AND ATTRIBUTES
2.4.1	Initiative and Willingness to Take Risks
2.4.2	Perseverance and Flexibility
2.4.3	Creative Thinking
2.4.4	Critical Thinking
2.4.5	Awareness of One's Personal Knowledge, Skills and Attitudes
2.4.6	Curiosity and Lifelong Learning
2.4.7	Time and Resource Management
2.5	PROFESSIONAL SKILLS AND ATTITUDES
2.5.1	Professional Ethics, Integrity, Responsibility and Accountability
2.5.2	Professional Behavior
2.5.3	Proactively Planning for One's Career
2.5.4	Staying Current on World of Engineering
3	**INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION**
3.1	TEAMWORK
3.1.1	Forming Effective Teams
3.1.2	Team Operation
3.1.3	Team Growth and Evolution
3.1.4	Leadership
3.1.5	Technical Teaming
3.2	COMMUNICATIONS
3.2.1	Communications Strategy
3.2.2	Communications Structure
3.2.3	Written Communication
3.2.4	Electronic/Multimedia Communication
3.2.5	Graphical Communication
3.2.6	Oral Presentation and Inter-Personal Communications
3.3	COMMUNICATION IN FOREIGN LANGUAGI
3.3.1	Communication in English
3.3.2	Communication in Intra-EU Languages
3.3.3	Communication in Extra-EU Languages
4	**CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT**
4.1	EXTERNAL AND SOCIETAL CONTEXT
4.1.1	Roles and Responsibility of Engineers
4.1.2	The Impact of Engineering on Society
4.1.3	Society's Regulation of Engineering
4.1.4	The Historical and Cultural Context
4.1.5	Contemporary Issues and Values
4.1.6	Developing a Global Perspective
4.2	ENTERPRISE AND BUSINESS CONTEXT
4.2.1	Appreciating Different Enterprise Cultures
4.2.2	Enterprise Strategy, Goals and Planning
4.2.3	Technical Entrepreneurship
4.2.4	Working Successfully in Organizations
4.3	CONCEIVING AND ENGINEERING SYSTEM
4.3.1	Setting System Goals and Requirements
4.3.2	Defining Function, Concept and Architectu
4.3.3	Modeling of System and Insuring Goals Can Be Met
4.3.4	Development Project Management
4.4	DESIGNING
4.4.1	The Design Process
4.4.2	The Design Process Phasing and Approaches
4.4.3	Utilization of Knowledge in Design
4.4.4	Disciplinary Design
4.4.5	Multidisciplinary Design
4.4.6	Multi-Objective Design (DFX)
4.5	IMPLEMENTING
4.5.1	Designing the Implementation Process
4.5.2	Hardware Manufacturing Process
4.5.3	Software Implementing Process
4.5.4	Hardware Software Integration
4.5.5	Test, Verification, Validation and Certifica
4.5.6	Implementation Management
4.6	OPERATING
4.6.1	Designing and Optimizing Operations
4.6.2	Training and Operations
4.6.3	Supporting the System Lifecycle
4.6.4	System Improvement and Evolution
4.6.5	Disposal and Life-End Issues
4.6.6	Operations Management

Flows with Friction Drag and Lift and Design & Professional Skills
Projects by Dr Mushtak Al-Atabi & Dr Abdulkareem S. Mahdi
This module is assed as follows

1. Final Exam 60%
2. Group Project 40%

A number of group Projects are offered this semester. This project is one of them

Conceive, Design, Implement & Operate a Small Wind Turbine using a Standard Airfoil

This project involves the review of the report “Wind Tunnel Aerodynamic Tests of Six Airfoils for Use on Small Wind Turbines” by Michael S. Selig and Bryan D. McGranahan (a copy of the report will be made available to the students) and selecting the more efficient airfoil to assess using wind tunnel testing experiments.

The results of the study will serve as confirmation of the techniques and measuring equipments used by us as they are compared to the Selig and McGranahan report.

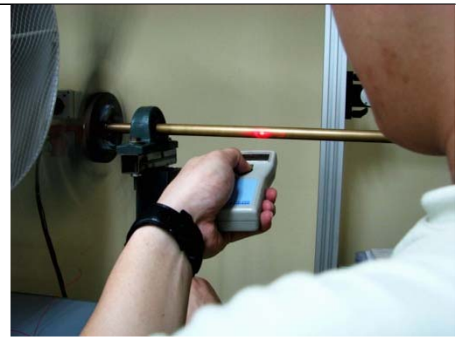
The project will involve the following

1. Assessing the test results for the six airfoils reported by Selig and McGranahan and selecting one “optimum” airfoil based on clear selection criteria. The selection must be approved by the lecturers.
2. Constructing a wing that follows the selected airfoil profile using the CNC machine and designing a mounting so that it can be tested in Taylor’s subsonic wind tunnel.
3. Measuring the drag and lift on the wing and comparing it to the data of Selig and McGranahan.
4. Performing flow visualisation studies using smoke flow visualisation, tuft flow visualisation, and surface flow visualisation on the wing to deduce the flow structures.
5. Developing a wind turbine using the selected wing, assessing its performance and comparing that to the theoretical calculations.
6. Writing a paper about the project following the “instructions for

Figure 2: Sample handout for the projects offered.

Table 2: A matrix linking CDIO syllabus to the learning outcomes developed by the two modules considered in this study.

CDIO Syllabus Item	"Flows with Friction, Drag & Lift" Learning Outcomes	"Design & Professional Skills" Learning Outcomes
1.1 Knowledge in Underlying Sciences	1, 4	
1.2 Core Engineering Fundamental Knowledge	2, 5	
2.1 Engineering Reasoning & Problem Solving		
2.2 Experimentation & Knowledge Discovery	5	3
2.3 System Thinking		5
2.4 Personal Skills & Attributes		1, 2,4
2.5 Professional Skills & Attitudes		4,6
3.1 Teamwork		2
3.2 Communications		1
4.1 Societal & External Context		4,5
4.2 Enterprise & Business Context		4,6
4.3 Conceiving & Engineering Systems		4
4.4 Designing	3	7
4.5 Implementing		7
4.6 Operating		5

a. Flow structures around wind turbine.

b. Student measuring the wind turbine airfoil speed.

c. Magnus effect wind turbine.

d. Conventional wind turbine.

Figure 3: Samples of students' projects.