DESIGN OF CDIO CURRICULUM FOR UNDERGRADUATE ENGINEERING PROGRAMME: INDIAN CONTEXT

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ABSTRACT

Autonomous institutions in India have the freedom to design and develop innovative curriculum, content delivery, and assessment methodologies. In 2013, the Outcome-Based Education (OBE) framework was made mandatory for accrediting undergraduate engineering programs in India by the National Board of Accreditation (NBA). However, in reality, cognitive aspects are addressed to a greater extent than the affective and psychomotor aspects of learning. After attending the 11th International CDIO conference, we realized that the CDIO framework would be highly suitable for improving the undergraduate engineering curriculum in addressing all 12 graduate attributes of the International Engineering Alliance (IEA). As a pilot study, *Engineering Design* and *Capstone* courses were introduced in the OBE curriculum at our institute to emphasize hands-on practices, personal and interpersonal skills. These courses helped us to strengthen the mapping between course outcomes and 12 graduate attributes/program outcomes. This motivated us to adapt the CDIO curriculum for all undergraduate engineering programs at our institution in 2018. The major challenge was in the introduction of new courses in the curriculum such that all four sections of the CDIO syllabus are addressed within the framework given by the regulatory authorities in India. This paper presents the methodology followed in adapting the CDIO syllabus at our institution, satisfying the requirements of regulatory authorities in India. In the proposed CDIO curriculum, a specialized new course was introduced at each semester of the program to improve the personal, interpersonal, and system building skills of the students, in addition to disciplinary knowledge and reasoning. The courses are, namely, *Engineering Exploration*, *Lateral Thinking*, *Design Thinking*, *Project Management*, *System Thinking*, *Engineering Design Project*, *Capstone Design Project,* and *Major Project*. The course outcomes of all the courses in the curriculum are articulated by combining the knowledge, skill, and attitude domains of learning. A model CDIO curriculum designed for Electronics and Communication Engineering program is presented in this paper.

KEYWORDS

Curriculum Design, Graduate Attributes, Course Outcomes, Programme Outcomes, Standards 1, 2, 3, 4, 5

INTRODUCTION

Engineering education programs throughout much of the 20th century offered students plentiful hands-on practices. Accomplished and experienced engineers taught courses that focused on solving tangible problems. In due course of time, due to rapid advancement in science and technology, engineering education drifted towards the teaching of engineering science. Teaching engineering practice was increasingly de-emphasized. As a result, industries in recent years have found that graduating students, while technically adept, lack many abilities required in real-world engineering situations. To address the increasing gap between scientific and practical engineering demand and to meet the global requirements of professional Engineers, the CDIO curriculum was introduced.

All India Council for Technical Education (AICTE), Government of India, has taken many initiatives in recent years to recalibrate the technical education in India. The initiatives include the development of model curriculum for undergraduate engineering programs, self-learning content through MOOCs, a new policy for the training of technical teachers, three-week student induction program, enunciating guidelines for the mandatory internship and examination reform policy to examine the effectiveness of earlier initiatives of AICTE and also those on the anvil (All India Council for Technical Education, 2018).

Our institution, Thiagarajar College of Engineering (TCE), Madurai, was granted autonomous status in the year 1987 by the University Grants Commission (UGC), New Delhi. This has given us the freedom to design and develop an innovative curriculum in alignment with the guidelines of AICTE and Affiliating University, content delivery, and assessment methods. As a major initiative in the teaching and learning process, a competency-based curriculum Bloom's taxonomy based course learning outcomes & assessment methodologies were introduced in 2008. As Outcome-Based Education (OBE) has been made mandatory for accrediting Engineering Programmes in India, the curriculum was suitably modified in the year 2014 (TCE-OBE Syllabus, 2014). Though the undergraduate program curriculum is designed based on the OBE framework, the hands-on practices, system/design thinking leading to product development, and interpersonal skills have not been much emphasized in the curriculum. Cognitive aspects are addressed to a greater extent than affective and psychomotor.

After attending the 11th International CDIO conference at Chengdu, China, we realized that a CDIO based curriculum is organized around the disciplines, but with CDIO activities are interwoven. The CDIO activities include projects, internships in industry, and active learning in theory and practical courses in which modern state-of-art laboratories are considered as workspaces (Johan Bankel et al., 2005). CDIO framework has been implemented in many universities all over the world as it maps with the Washington Accord graduate attributes. It motivated us to introduce 'Engineering Design' and 'Capstone' courses in our OBE curriculum as an experimental basis to emphasize hands-on practices, system/design thinking, and interpersonal skills. These courses helped us to improve the coverage of attainment of graduate attributes/program outcomes and student engagement.

However, we felt that the transition from the existing model to the CDIO framework would be more challenging. In the interaction with faculty members from various Universities at CDIO international conferences and Asian Regional meetings, we understood the challenges in implementing the CDIO framework first time in a country. In this connection, the authors explained the steps to be followed in designing the CDIO curriculum first time in a country. They described the design and implementation of the CDIO framework based design directed Engineering Curriculum in Shantou University, China (Gu et al., 2006). This has given us the confidence to implement the CDIO curriculum first time in India, as we had strong support from the administration and commitment from the faculty members. With this motivation, we adapted the CDIO syllabus (Edward, Johan, William, & Doris, 2011) for all seven undergraduate engineering programs at our institution from the academic year 2018-19.

The rest of the paper is organized as follows. The development of the TCE-CDIO curriculum is described in the following section. After that, an example CDIO course is discussed in the context of template, Program outcome (PO) mapping, and reflection.

TCE - CDIO CURRICULUM DESIGN ACTIVITIES

CDIO core committee was formed at TCE comprising of two faculty members from each department under the leadership of Dean (Academic Process) and Dean (Research and Development). These faculty members were chosen based on their proficiency in curriculum design. A series of workshops were conducted for the core committee members to enrich the exposure in the CDIO syllabus (Edward F. Crawley, 2001). After a series of discussions among the CDIO core committee members, templates for the CDIO curriculum at TCE addressing the four sections of CDIO syllabus and course design were designed, and a new proficiency scale named as TCE Proficiency Scale (TPS) was formed, as shown in Table 1. The core committee members conducted workshops to their respective department faculty members on CDIO syllabus, CDIO standards, three domains of Bloom's taxonomy (Cognitive, Affective & Psychomotor), and TCE Proficiency Scale.

Table 1. TCE Proficiency Scale (CDIO Curriculum Framework)

TPS	Proficiency	Cognitive	Affective	Psychomotor
TPS1	To have been exposed to	Remember	Receive	Perception, Set
TPS2	To be able to interpret and Imitate	Understand	Respond	Guided Response
TPS3	To be skilled in the Practice or Implement	Apply	Value	Mechanism
TPS4	To be able to participate in and contribute	Analyze	Organize	Complex Overt Responses
TPS5	To be able to judge and adapt	Evaluate	Organize	Adaptation
TPS6	To be able to lead and innovate	Create	Characterize	Origination

Table 2. CDIO Courses at TCE

Semester	Course	Course type	Credits	CDIO
I	Engineering Exploration	Practice Dominated Theory	3	C
II	Lateral Thinking	Practice Dominated Theory	1	C
III	Design Thinking	Practice Dominated Theory	2	C(D)
IV	Project Management	Practice Dominated Theory	3	C(D)(I)
V	System Thinking	Practice Dominated Theory	3	CD(I)
VI	Engineering Design Project	Project	3	CDI(O)
VII	Capstone Design Project	Project	2	CDIO
VIII	Major Project	Project	9	CDIO
Total Credits for CDIO courses			**26**	

A set of new courses were identified and diligently scheduled without violating AICTE model curriculum requirements on technical knowledge and reasoning. About 20% of total credits have been allocated to CDIO courses. The semester-wise CDIO courses, common to all undergraduate engineering programs, are listed in Table 2.

The detailed syllabi for these courses were prepared by CDIO core committee members and reviewed by a section of final year students, Senior Faculty members, employers, and recently passed out alumni.

TCE-CDIO CURRICULUM

The TCE-CDIO curriculum was designed in the context suitable for India. The four sections of the CDIO syllabus, namely *'Technical Knowledge and Reasoning, Personal and professional skills, Interpersonal skills, and CDIO'* are addressed in the curriculum by introducing new courses and redesigning previous courses. A systematic process was followed to design the CDIO curriculum such that the new curriculum is more coherent and better focussed than the previous version and offers more flexibility to students in choosing their preferred area of specialization.

Based on the inputs namely CDIO Syllabus 2.0, Guidelines of Regulatory Authorities, Guidelines by professional societies such as American Society for Mechanical Engineering (ASME), Institute of Electrical and Electronics Engineering (IEEE) etc., on Curriculum Design, Washington Accord Graduate Attributes/Programme Outcome, Credit distributions at reputed higher learning institutions in India and abroad and the feedback report on existing Curriculum by Students, Faculty members, Employers, Alumni, the Dean (Academic Process) design Institution's Regulation of Undergraduate Programme. The regulations cover the Minimum Number of Credits to be earned, Credit Distribution, Policies on Assessment, Internship, Community Projects, and Industry Supported courses. The CDIO core committee is authorized to design Specialized Courses on CDIO.

AICTE, India has proposed the model curriculum for four-year undergraduate engineering programs in January 2018 to improve the quality of technical education in India. The AICTE model curriculum stipulates total number credits, course categories, and their credit distribution to design curriculum. However, AICTE, India permits autonomous institutions to make minor variations in the credit distributions. Based on this, we have made the credit distribution, including the Specialized CDIO courses at TCE. The credit distribution at TCE is given in Table 4.

In order to synergize academic and sponsored research activities with the teaching and learning process, Special Interest Groups (SIG) were created. Each engineering department has a theme area based on faculty expertise and infrastructure. The faculty members attached to SIGs have been empowered to design courses and foster industrial linkage in the respective domains and theme areas of the department. This innovative approach has enabled sustained academic excellence at our institution. Further, it also motivated to redraft the curriculum and syllabi of courses pertaining to SIG. Based on Programme Outcomes (POs) and the reports of feedback by internal and external stakeholders of a particular engineering program.

Table 3. TCE Curriculum Design Process

Inputs:

- *CDIO Syllabus 2.0*
- *Guidelines of Regulatory Authorities*
- *Professional Societies Guidelines on Curriculum Design*
- *Washington Accord Graduate Attributes/Programme Outcome*
- *Credit distributions at higher learning institutions*
- *Feedback Report on existing Curriculum by Students, Faculty members, Employers, Alumni*

Process

- *Development of Institution's Regulation of Undergraduate Programme by Dean (Academic Process) covering the following*
    - *Minimum Number of Credits to be earned, Credit Distribution, Policies on Assessment, Internship, Community Projects, Industry Supported courses*
- *Design of Specialized Courses on CDIO by CDIO Core Committee Members*
- *Preparation of 'Scheduling of Courses' at a program level, covering the all the four sections of the CDIO Syllabus*
- *Identification of the courses under each category of credit distribution and its type of implementation. The type includes theory, practical, Practice dominated Practical, Theory Dominated Practice course, Project.*
- *Review of 'Scheduling of Courses' by CDIO Core committee and incorporation of suggestions by the core committee*
- *Course Design as per the Course as per the Course Design Template by Core Committee*
    - *The courses are designed by faculty members in a relevant Special Interest Group(SIG)*
- *Review of Scheduling of Courses and detailed syllabus for each course at Board of Studies Meeting and incorporation of suggestions by the members.*
- *Review of Curriculum and Syllabus of the engineering programs at Academic Council Meetings and Approval is given for implementation after the incorporation of suggestions by the members*

Output

- *Regulations for Undergraduate Engineering programs at the institute*
- *TCE- CDIO curriculum*

The program, the course outcomes are identified in each SIG. Subsequently, courses for each curricular component in each Special Interest Group (SIG) are identified. Based on this and the Institution's Regulations, courses are classified as Core or Professional Elective Course. There are five types of courses in the TCE-CDIO Curriculum. They are theory courses, Practical Courses, Theory dominated Practical courses, Practice dominated Theory courses, and projects. The department level coordinator prepares a course map for the program in discussion with coordinators of SIGs in the department and 'Scheduling of Courses' in alignment with the CDIO curricular components and Regulations of TCE-CDIO Curriculum. This is followed by assigning credits and type for each course. The scheduling of courses is presented at the CDIO Core Committee to review the "Scheduling of Courses' and suggestions given by members are incorporated. The 'Scheduling of Courses' for Undergraduate Electronics and Communication Engineering (ECE) programme is presented in Table 5. Syllabus for each course is designed using 'Concept Map' for each course by SIG faculty members in the respective department, and eventually, a consolidated syllabus is formed. The Department of ECE has the following SIGs.

1. Microwave Engineering
2. Signal Processing
3. Image Processing
4. Communication Networking
5. VLSI Systems
6. Embedded Systems

Table 4. Credit Distribution for Undergraduate Engineering Programmes

S.No	Category	Suggested Credits* by AICTE	Credits at TCE
1	Humanities and Social Sciences including Management Courses	12	9-11
2	Basic Science courses	25	21
3	Engineering Science courses	24	23-26
4	Professional core courses	48	55
5	Professional Elective courses relevant to chosen specialization/branch	18	18 -24
6	Open subjects – Electives from other technical and /or emerging subjects	18	12 -18
7	Project work, seminar, and internship in industry	15	15
8	Mandatory Courses [Environmental Sciences, Induction Program, Indian Constitution, Essence of Indian Traditional Knowledge]	Non Credit	Non Credit
	Total (TCE: Minimum Credits to be earned for the award of the degree)	**160**	**160**

**Minor Variation is allowed as per the need of the respective disciplines*

The first step of SIG based course design is to identify course designers from each SIG. The course designers prepare/ redefine course outcomes with corresponding Bloom's level and target level of attainment. Then, designers ensure that the course outcomes are correlated with Programme Outcomes. After this, designers form Bloom's taxonomy based assessment pattern followed by preparation of concept map, course content, lecture schedule, and course level assessment questions. Then, the course design (syllabus) is presented in the SIG meeting for review and to incorporate suggestions given by SIG members. After the syllabus is designed for all the courses following the process discussed above, and the final syllabus is formed. The professional core courses designed by each SIG for ECE undergraduate Programme are listed in Table 6.

The syllabus is reviewed in the Board of Studies (BoS) meeting. The composition of the Board of Studies is two academic experts in the program, industry experts, faculty members nominated by affiliating University, Alumni, faculty members in the respective department, and student nominees. After incorporating suggestions from the BoS members, the syllabus is forwarded to the Academic Council for approval. The academic council is the highest authority for reviewing and approving the academic regulations of the institute and syllabus of all the programs in the institution. After incorporating suggestions from the Academic Council members, the syllabus is distributed to the faculty members and students.

One of the CDIO courses, namely 'Design Thinking,' is given as an example. The Course outcomes (COs) are given in Table 7. The Course outcomes mapping with CDIO Curricular components and TCE proficiency scale are illustrated in Table 8.

Table 5. Scheduling of Courses (B.E. ECE Programme)

Sem-ester	**Theory/ Theory cum Practical**						**Practical**		***CDIO Courses***	**Credits**
I	18MA110 Engineering Calculus (4)	18PHB20 Physics (3)	18CHB30 Chemistry (4)	18EG180 English (2)	-	18ME160 Engg Graphics (4)	18EG170 English Lab. (1)	18PH180 Physics Lab. (1)	*18ES150 Engg Exploration (3)*	22
II	18MA210 Matrices and Differential Equations (3)	18EC220 Network Theory (3)	18EC230 Electronic Devices (3)	18EC240 Semiconductor Physics (3)	-	18EC260 Digital System Design (3)	18EC270 Circuits and Devices Lab (1)	18EC280 Workshop (1)	*18ES290 Lateral Thinking (1)*	18
III	18EC310 Complex Analysis and Linear Algebra (3)	18EC320 RF Passive Devices and Circuits (3)	18EC330 Electronic Circuits (3)	18EC340 Signals and Systems (3)	18EC350 Microprocessors and Microcontrollers (3)	18EC360 Programming for Problem Solving (3)	18EC370 Microprocessor and Microcontroller Lab (1)	18EC380 Electronic Circuits Lab (1)	*18ES390 Design Thinking (2)*	22
IV	18EC410 Optimization and Numerical Methods (3)	18EC420 RF Active Circuits (3)	18EC430 CMOS VLSI Systems (3)	18EC440 Signal Processing (3)	18YYFX0 Foundation Elective I (3)	18EG460 Professional Communication (2)	18EC470 RF Circuits Lab (1)	18EC480 Signal Processing Lab (1)	*18EC490 Project Management (3)*	22
V	18EC510 Data Communication Networks (3)	18EC520 Antenna and Wave Propagation (3)	18EC530 Analog and Digital Communications (3)	18ECPX0 Prog. Elective I (3)	18YYGX0 General Elective (3)	18EC560 Digital Image Processing (3)	18EC570 Data Communication Networking Lab (1)	18EC580 ADC Lab (1)	*18ES590 Capstone Design Project (3)*	23
VI	18EC610 Accounting and Finance (3)	18EC620 Control Systems (3)	18EC630 Data Structures (2)	18ECPX0 Prog. Elective II (3)	Program/ Foundation Elective (3)	Engineering Sciences Elective (3)	18EC670 Commn System Design Lab (2)	18EC680 Data Structures Lab (1)	*18ES690 Engg Design Project (3)*	23
VII	18ECPX0 Prog. Elec.III (3)	18ECPX0 Prog. Elec IV (3)	18ECPX0 Prog. Elec. V (3)	18ECPX0 Prog. Elec. VI (3)	-	-	18EC770 Elective Lab (1)	-	*18ES790 System Thinking (2)*	15
VIII	18XXPX0 Prog. Elec. VII (3)	18XXPX0 Prog. Elec. VIII (3)	-	-	-	-	-	-	*18EC810 Project (9)*	15

Table 6. Professional Core Courses in ECE Programme

Microwave Engineering: • RF Passive Devices and Circuits • Electronic Circuits • Electronic Circuits Lab • RF Active Circuits • RF Circuits Lab • Antenna and Wave Propagation **VLSI Systems:** • Network Theory • Electronic Devices • Semiconductor Physics • Digital System Design • Circuits and Devices Lab • Electronic Circuits • Electronic Circuits Lab • CMOS VLSI Systems **Image Processing:** Digital Image Processing	**Signal Processing:** • Signal Processing • Signal Processing Lab • Analog and Digital Communication Systems • Analog and Digital Communication Lab • Control Systems • Communication System Design Lab • Wireless Communications **Networking:** • Problem Solving Using Computers • Data Structures • Data Structures Lab • Data Communication Networks • Data Communication Networking Lab **Embedded Systems:** • Microprocessors and Microcontroller • Programming • Microprocessor and Microcontroller Lab • Electronics Workshop

Table 7. Course Outcomes of Design Thinking Course

CO Number	Course Outcome Statement	Weightage in %
On the successful completion of the course, students will be able to		
CO1	Identify a specific social need to be addressed	20
CO2	Identify stakeholder's requirements for the societal Project	20
CO3	Develop measurable criteria in which design concepts can be evaluated	10
CO4	Develop prototypes of multiple concepts using user's feedback	30
CO5	Select the best design solution among the potential solutions with its functional decomposition	20

Table 8. Course Mapping with CDIO Curricular Component and TCE Proficiency Scale

CO #	TCE Proficiency Scale	Learning Domain Level			CDIO Curricular Components (X.Y.Z)
		Cognitive	Affective	Psychomotor	
CO1	TPS3	Apply	Value	Mechanism	1.1, 1.2, 2.1.1, 3.1.2, 3.2.3, 3.2.6, 4.1.2
CO2	TPS3	Apply	Value	Mechanism	1.1, 1.2, 2.1.2, 2.5.1, 2.5.2, 3.1.2, 3.2.3, 3.2.6, 4.1.2
CO3	TPS3	Apply	Value	Mechanism	1.1, 1.2, 2.1.3, 3.1.2, 3.2.3, 3.2.6, 4.1.2, 4.3.1
CO4	TPS3	Apply	Value	Mechanism	1.1, 1.2, 2.1.4, 3.1.2, 3.2.3, 3.2.6, 4.1.2, 4.4.1
CO5	TPS5	Evaluate	Organize	Adaptation	1.1, 1.2, 2.1.5, 3.1.2, 3.2.3, 3.2.6, 4.1.2, 4.4.1

CO to PO Mapping with three correlations levels are shown as follows:
It can be observed that almost all the program outcomes are addressed with a significant correlation level. Similar observations were found in the so for conducted CDIO courses, and the same will be done for higher semester CDIO courses. The involvement of students in CDIO courses was really encouraging. They demonstrated their design thinking skills and showcased their work in exhibitions and conferences, for which they won awards and laurels. The summary of the course exit survey of students for this CDIO course is shown in Figure 1.

CONCLUSION

In TCE, CDIO curricular education framework is adapted for seven undergraduate engineering programs, namely Civil Engineering, Mechanical Engineering, Electrical and Electronics Engineering, Electronics and Communication Engineering, Computer Science and Engineering, Information Technology, and Mechatronics in alignment with guidelines by the Indian regulatory authorities. The new curriculum, introduced in the academic year 2018-19, gives more choices to choose the courses as per the student's preferred area of specialization. The courses in this program have been developed using the TCE Proficiency scale and CDIO curricular components. A new proficiency scale is defined by combining knowledge, skills, and affective domain learning. Also, the mapping of COs with CDIO curricular components are included in the course syllabus. In the proposed curriculum, a new specialized course was introduced at each semester of the program to improve the personal, interpersonal, and system building skills of the students, in addition to the disciplinary knowledge and reasoning. The courses are namely Engineering Exploration, Lateral Thinking, Design Thinking, Project Management, System Thinking, Engineering Design Project, Capstone Design Project, and major project. Designing and adapting the CDIO curriculum framework has helped us in significantly addressing all the three domains of learning, thereby strengthen the mapping between course-level learning outcomes and all 12 graduate attributes.

Figure 1. Course exit survey

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BIOGRAPHICAL INFORMATION

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