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Implementation of the CDIO Framework in Engineering Courses to Improve Student-Centered Learning

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Abstract: The proposed work discusses the progress of engineering curriculum development and the advancement of the engineering learning ecosystem. While technology advances around the pupils, engineering principles and methods remain static. The objective of this paper is to investigate self-directed learning and collaborative learning ways among CDIO curriculum batch of students using Active Learning Techniques (ALT). The learning ecosystem for students to grasp and generate a creative solution for a complex problem connected to their academic application was discovered in the suggested work's framework. The article explains how instructors can prepare students for next-generation industrial readiness by using an active learning technique that emphasizes both intellectual and practical learning. The study's focus is on novel material delivery strategies, demo-based peer training, and project-based learning activities that address cognitive and kinesthetic skills of students. The CDIO education framework for electrical machines course is described here, as well as the syllabus structure, cognitive level approach, and kinesthetic level approach, all of which improved engineering education topology.

***Keywords*—**Electrical machine, cognitive skills, kinesthetics skills, blooms taxonomy.

I. INTRODUCTION

Curriculum framework made a solid backbone in higher engineering education for driving the teaching learning process. Over time, the creation and adaptation of curriculum in the engineering area has been successful in reducing the transition rate among students learning ecology Sheppard et al. The evolution of the Conceive, Design, Implement, and Operate (CDIO) curricular framework introduced theoretical knowledge combined with practice and a prototyping technique based on theory to improve student ideation Crawley, E et al. (2014). In every suggest course, the CDIO curriculum model defines intellectual and practical student learning Edstrom k et al. (2014). In engineering courses, the use of active learning strategies combined with curriculum motivates weak and indifferent students to be active during the course Fusic et al. (2018).

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Students are expected to reinforce the underlying theories while also gaining practical experience in these disciplines thanks to the project-based teaching technique. This allows pupils to more effectively examine and solve challenges Paul Crilly et al. (2014). For the semiconductor circuit design course at Hamburg University of Technology (TUHH), a new teaching strategy (e-learning, video lectures, peer training, etc.) was implemented Aljoscha Reinert et al. It improves the lecture environment by loosening up the atmosphere and increasing student involvement in the learning process. Peer teaching is a method of acquiring knowledge and skills by enlisting the active assistance and support of matched partners Julius fusic et al. (2018). Both professors and students profit from the increase of peer teaching and learning in engineering education Keith J. Topping et al. Massive open online courses (MOOCs) solidified a number of elements to improve the online learning experience. To examine the factors that influence motivation and the learning ecology, a gamification cooperative MOOC model was built and implemented by Oriol borras-gene et al. Traditional teaching and learning approaches are no longer effective for students. In order to engage students, new teaching and learning approaches must be offered, as engagement has an impact on learning outcomes and motivation. GBL (game-based learning) is a novel technique to engage students in learning by including activities and exciting events Azita Iliya et al. Every engineering curriculum must use the flipped classroom activity as one of the active learning tactics for their pupils Kumar Yelamarthi et al. Every engineering discipline must produce critical thinking, and this skill development is lacking in passive learning (conventional classroom learning with the professor teaching and the students listening) Jeffrey L. Duffany. Undergraduate students can work as peer learning assistants (PLA) in labs, exhibits, and activities, among other places. PLAs do a variety of roles depending on the course, including properly managing class hours, assisting students in labs, and supporting group projects I. Pivkina et.al (2016). Project-based learning addresses higher-order cognitive challenges while also taking into account the student's learning interests Elham H. Fini et al. (2018) and Preeti Thakur et al. (2021).

According to the research, the creative strategy simply made pupils more focused on their classes than the traditional approach. The first section of this paper covers the introduction and a literature review. The learning strategies and activities used to engage students during in-class sessions are demonstrated in section II. The proposed course's instruction content and research methodology are detailed in section III. The case study scenario for the CDIO curriculum-based Electrical Machine course is presented in section IV. The results of the OBE, CBCS, and CDIO curriculum frameworks, as well as the assessment of project-based learning rubrics, are discussed in section V. The conclusion and future work to engage the audience are presented in section VI.

II. LEARNING STRATEGIES AND ACTIVITY APPROACH

As illustrated in Figure 1, the learning ecosystem in engineering courses is divided into formal and informal learning approaches. In engineering education, the organized approach focuses on Conventional Learning Methods, whereas the unplanned activity approach applies Innovative Learning Methods. In general, formal learning strategies promote cognitive level skills, while informal learning techniques stress emotive and kinesthetic level skills. The implementation of an informal learning technique accelerated students' development of self-directed learning and a collaborative learning environment both within and outside of the classroom Azita Iliya et al. The heart of the Conceive Design Implement and Operate (CDIO) education paradigm is innovative teaching strategies such as flipped classrooms, project-based learning, and activity-based learning. The following are some examples of in-class and out-of-class activities. Students in the proposed case study use an informal learning platform to pursue the CDIO curricular approach in engineering courses.

Typical assignments include:

- Written tasks
- Homework on problem solving

Assignments that are unique

- Tutorials that are flipped in the classroom
- Project-based assignment
- Demonstration
- Interaction with peers.

The following are the in-class activities that have all been proposed in the article case study. The class ecology is established as a virtual classroom based, collaborative learning based, and fulfilled class environment as a result of these informal learning approaches.

A. Technical Quiz

For student learning experience, the teacher developed and deposited learning resources, in-class peer lectures, and recorded videos in a repository. Plickers, which are similar to assessment tools, are used to offer a set of multiple-choice questions during an in-class quiz activity. Under Blooms remember pedagogy level, the instructor develops exam questions based on classroom discussion, important definitions, basic laws, and assertions. This made the students to get concentrate and engage with concept during learning activity. As a result, the formative evaluation is completed automatically in the assessment tool, and the students discuss the results later.

As a result of the impact of the Covid-19 pandemic, most education management from schools to higher education uses online platforms such as Pear deck, Quizizz, Nearpod, google forms, canvas, and others as in-class technical quiz activity interactive tools, which are implemented through online discussion platforms such as Zoom, G-meet, and Discord, as shown in figure 1.

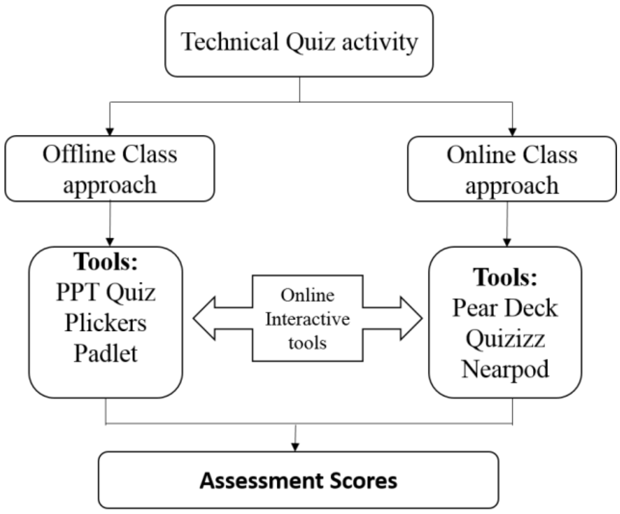

Fig. 1 Technical Quiz activity approach.

B. Flipped Classroom

The flipped classroom is a lesson-based interactive in-class strategy. Students' class activities and homework or assignment activities are inverted as part of the self-directed method. The flipped class is mostly student-centered, with a focus on conceptual understanding of a particular topic. Initially, the instructor or facilitator made video or virtual paced course content and distribute it well ahead of the scheduled class. Students need browse through the repository's learning resources and discuss the subject with student groups or have their questions answered by facilitators via the internet. The facilitator asks questions or assigns activities as a tutorial assignment during class. Students might solve issues or complete activities depending on what they learned outside of class. The teacher framework influences activities such as affinity mapping, higher order problem solving, and Think Pair and Share (TPS).

C. Demonstration (Demo)

During a project-based learning exercise, Demo-based learning paved the way for a fresh idea. The instructor may construct a prototype model for a specific student or a group of students, and the prototype should always be connected to the faculty's topic. The students then defend the topic by explaining it with a chart or a power point presentation, along with an application demonstration. Rubrics are used to assign grades and assess students.

D. Survey/Polls

Students are asked to answer survey questions and complete the survey using Google Forms or the Plickers, Polls Everywhere survey app. On the basis of this, a comparison of project-based learning and traditional learning is made. The student/learner focus learning method is identified as a result of this. In addition, the survey includes a summary of student satisfaction with learning practices.

E. Project-Based Learning (PBL) Activity

The project-based learning task is frequently used to determine a student's kinesthetic level. The activity is self-directed as an individual or a group to put the theoretical concepts covered in the course into practice, develop, and simulate them. The PBL is an end-of-course activity or assignment for internals that assesses the course outcome. The teacher grades the students based on research questions such as how well they can combine all of their prior knowledge to create a creative solution to the instructor's problem statement. The informal exercise is primarily used to assess higher order cognitive and kinesthetic level components.

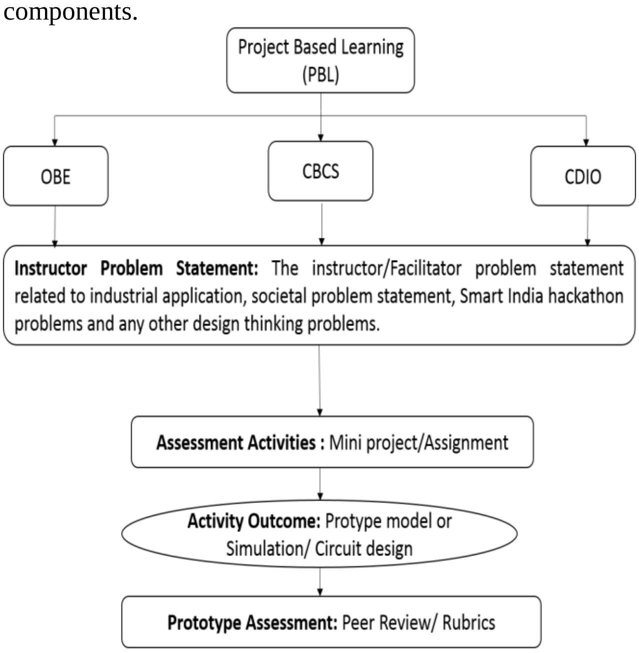

Fig. 2 Overview of Project-based approach in proposed case study

Problem-based learning is already replaced by project-based learning. The importance of empathy and psychomotor abilities among engineering students is highlighted by the introduction of the CDIO framework by crawler in 2007. The integration of theory and laboratory as a particular course in the engineering sector within the category of theory and practical courses. The engineering course structure and objectives are being changed in order to mold students into industry-ready engineers. The growth of the CDIO framework from OBE (outcome-based education) places a greater emphasis on kinesthetic ability among engineering students. The project-based activity strategy to be used in the article example is depicted in Figure 2.

III. Instructional Materials and Research Methodology

The research effort is organized around the introduction of a variety of informal activities and strategy structures in a variety of scenarios, for which case studies are required to investigate course and activity outcomes. The Electrical Machines course emphasizes learning through lectures, hands-on experiences in the laboratory, and a case study that discusses new learning ecology concerns.

A. Course design and pedagogy

The course uses 18MT220- Electrical Machines from the undergraduate mechatronics programme at Thiagarajar College of Engineering (TCE) in Madurai, Tamilnadu, as a case study. The course consists of three theory hours and two practical hours per week. Each session is 45 minutes long, with a proposed lecture plan based on syllabus design pedagogy. Throughout the semester, the instructor shall adhere to the syllabus content map and course outcome framework. TCE initially followed the 14MT230 Electrical Machines course under OBE until the 2016 academic year Fusic et al. (2018). Following that, from 2016 to 2018, a Choice-based credit system was implemented in OBE.

TABLE I
Course Outcome and weightage for 18MT220 course.

CO No.	Course Outcome Statement	Weightage in %
CO1	Interpret the knowledge about machines and its principles in real world application.	5%
CO2	Explain the various types of Machines, principle and operation.	10%
CO3	Explain the construction and working principle of electrical machines.	15%
CO4	Illustrate the characteristics and performance components of electrical machines.	15%
CO5	Determine performance parameters of different machines to solve the problems related to its application.	15%
CO6	Select the suitable machine & working principle for a given situation and application.	40%

Finally, from May 2018 onwards, the new CDIO framework pedagogical syllabus for Electrical Machines is proposed in the Board of Studies, TCE. In the propose case study, the influence of the Electrical Machine course in the CDIO framework develops a wide range of abilities in comparison to the prior TCE curriculum. Table 1 shows the proposed course outcome for the 18MT220 Electrical Machines course. The apply (A) level higher order thinking skills are covered by the course outcome (CO6). Students in an electrical machine course may assess up to the Analyze (A*) level of assessment depending on instructor activities. As a result, the Cognitive assessment pattern is clearly enumerated in table 3 with marks split up. Summative assessments give to students at each mid-level continuous assessment test (CAT) and integrate in the final exam grade. The assignments are either informal or formal activities that the course instructor may design. The table 2 details about the relationship between the course syllabus with CDIO competencies. CDIO curricular components as mentioned by researcher Crawley et.al (2014).

TABLE 2
COURSE OUTCOME MAPPING WITH CDIO COMPONENTS

CO #	Learning Domain Level			CDIO Curricular Components (X.Y.Z)
	Cognitive	**Affective**	**Psychomotor**	
CO1	R	Receive	Perception	1.1,1.2
CO2	U	Respond	Guided Response	1.2,2.1.1,2.12,2.2.3,2.3.1,2.3.2,2.4.3,2.4.5,2.4.6,2.5.4
CO3	U	Respond	Guided Response	1.2,2.1.1,2.12,2.2.3,2.3.1,2.3.2,2.4.3,2.4.5,2,2.5.4
CO4	U	Respond	Guided Response	1.2,2.1.1,2.12,2.2.3,2.3.1,2.3.2,2.4.3,2.4.5,2.4.6
CO5	A	Value	Mechanism	2.1.1,2.1.2,2.1.3,2.1.5,2.2.3,2.3.1,2.3.2,2.4.1,2.4.3,2.4.4,2.4.6,2.5.4,3.1.5
CO6	A	Value	Mechanism	2.1.1,2.1.2,2.1.3,2.1.5,2.2.3,2.3.1,2.3.2,2.4.1,2.4.3,2.4.4,2.4.6 3.1.5

TABLE 3
COGNITIVE SKILL LEVEL ASSESSMENT FOR 18MT220 COURSE

Cognitive Levels	Continuous Assessment Tests			Assignment			Final Exam
	1	2	3*	1	2	3*	
Remember (R)	10	10		-	-	-	20
Understand (U)	30	20		-	-	-	40
Apply (A)	10	20	50	10	10	-	40
Analyse (A*)	-	-	-	-	-	10	-
Evaluate (E)	-	-	-	-	-	-	-
Create (C)	-	-	-	-	-	-	-

TABLE 4
KINESTHETIC SKILL LEVEL ASSESSMENT FOR 18MT220 COURSE

Psychomotor Skill	Mini project /Assignment/Practical Component
Perception	Brain storming, Technical Quiz
Set	-
Guided Response	Flipped classroom, Active Learning Techniques
Mechanism	Project-based Learning, Simulation
Complex Overt Responses	-
Adaptation	-
Origination	-

The asterisk in table 3 indicates that the continuous assessment test 3 is completed as project-based learning, and also that assignment 3 is utilized to evaluate each stage's progress in the project-based activity. Table 4 shows the kinesthetic (psychomotor) evaluation style for the 18MT220 Electrical Machines course. Table 4 is used to assess a student's presentation of prototype findings are made during Project-based learning. The CDIO curriculum topology offers curricular components for the affective domain, psychomotor domain, and cognitive domain as shown in table 2 Edstrom K et al. (2014). The relationship between course outcome (CO) and programme outcome (PO) is made obvious in all three assessments using the X.Y.Z components.

a. Course Assessment:

The student midterm test and course model efficacy are evaluated via cognitive assessment using Item analysis and the psychomotor assessment through Peer review and Rubrics method. The figure 3 explains the evaluation process of 18MT220 Electrical machine course.

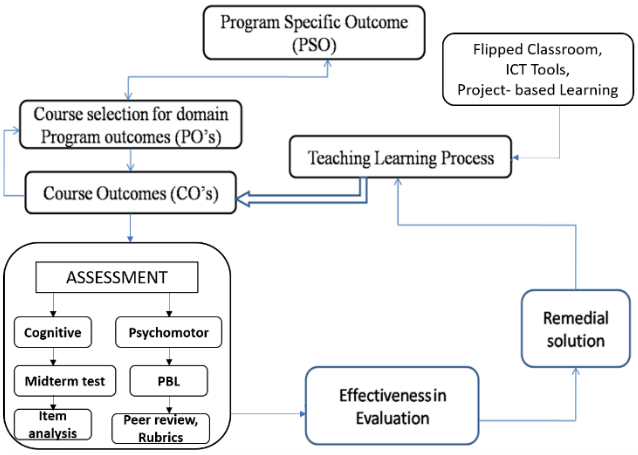

Fig. 3. Evaluation outline for Electrical Machines course

Based on the figure 3, the cognitive level assessment conducted for mid-term CAT 1 and 2 comprised of 50% MCQ and 50% written test for students. The third term was assessed by project-based assessment. The written communication was manually assessed by instructor whereas the MCQ questions were assessed using item analysis technique by Muhson Ali, et.al (2017).

TABLE 5
EVALUATION STANDARD SETTING IN ITEM ANALYSIS ASSESSMENT

DI	FV		
	> 0.3	**0.3 to 0.6**	**< 0.6**
Less than 0.2	Discard	Discard	Discard
0.2 to 0.3	Difficult	Improve	Easy
0.3 to 0.4	Improve	Accept	Improve
More than 0.4	Agree to take	Agree to take	Agree to take

The mid-term CAT 1 and 2 cognitive level assessment consists of a 50 percent MCQ and 50 percent written test for pupils. Project-based assessment was used to evaluate the third term. The instructor assesses the written communication, whereas the MCQ questions are evaluated using the item analysis technique by Muhson Ali, et.al (2017).

IV. CASE STUDY SCENARIO

The instructor paced approach or teacher centric conventional approach in content delivery is overcome in CDIO based curriculum. The 14MT230-Electrical machine course content delivery and conventional -based approach in previous curriculum were shown in Figure 4 and 5.

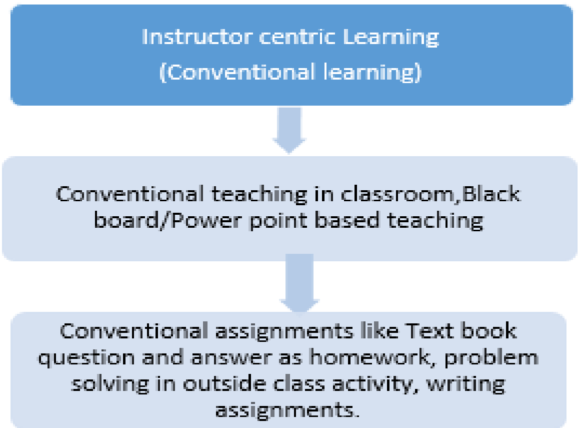

Fig 4: Content delivery approach for 14MT230 Course

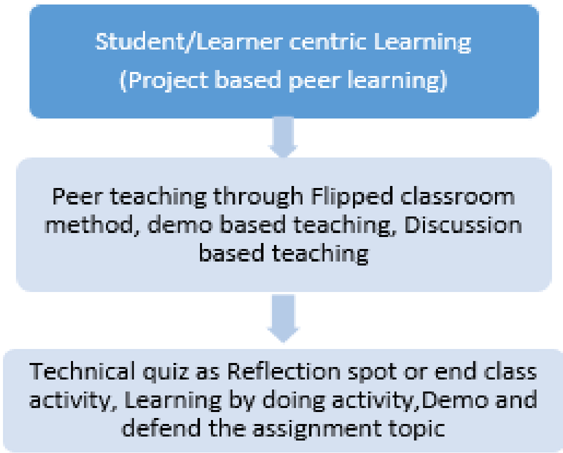

Fig 5: Content delivery approach for 18MT220 Course

A batch of students from Outcome based education (OBE) in 2015, a batch of students from Choice based credit system (CBCS) in 2018, and the final proposed batch of students from CDIO curriculum are being used to examine peer teaching and student-centered approach. CDIO Batch students only. The application of DC motor is taught as peer teaching by a postgraduate mechatronics student in order to cover course outcome 2 for the 18MT220 Electrical Machine course. Following the completion of content delivery for CDIO Batch students, a group task is assigned as a model Demo with power point and simulation presentation. The outcome of peer teaching was assessed through ALT activities as shown in figure 6 and 7 which includes technical quiz, flipped classroom tutorial, monoact, circuit debugging and project-based learning.

Fig 6: Peer Teaching Content delivery approach for 18MT220

Fig 7: Active Learning Strategy for proposed course.

The inflection points for all general engineering students who assume the electrical machine course as a common course to the students who now begin to have a domain specific attention for the course is supplied by the activity-based course curriculum development. Many students interpret the importance of electrical machine course in current engineering technology throughout PBL activities as indicated in figure 8.

Fig 8: Project-based learning presentation.

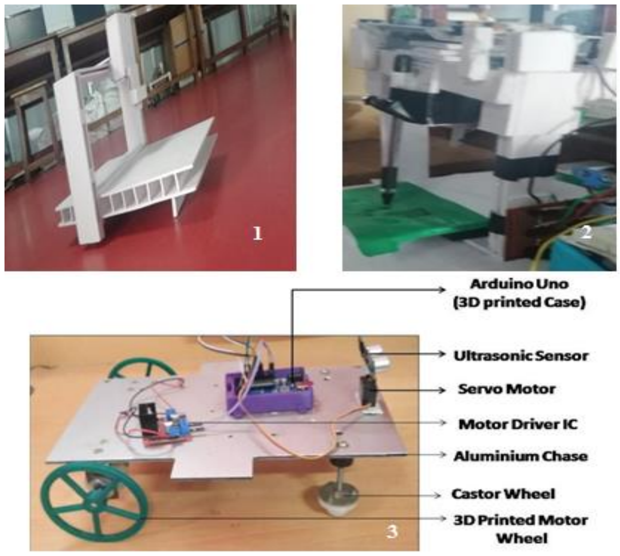

Fig 9: Project-based learning Prototypes

Figure 9 highlighted few models of prototypes like automatic drilling machine for foam board drilling, a low-cost plotter for jewel pattern design, a mobile robot for logistic applications.

V. Results and Discussion

The electrical machines course is a domain-specific mechatronics course meant to offer a technological foundation for all CDIO batch students. The CDIO framework's structured syllabus emphasizes the necessity of engineering students' strong development of cognitive, kinesthetic, and empathetic abilities. Students are teamed up at random in the suggested case study, with bright and slow learners mixed together. The team work together to create a prototype model using current technologies, and they actively participate in Active Learning Techniques (ALT) and other in-class activities. The CDIO framework clarifies engineering concepts such as lateral thinking and design thinking, allowing students to complete exercises in a well-structured and well-planned manner.

Students learn information and practice the theoretical concept into a prototype model as a result of the electrical machine course. The post-analysis approach for evaluating the quality and difficulty level of mid-term assessment test results for CDIO batch curriculum 2020 batch students is shown in table 6. All courses require a post-analysis to explore the topic from the student's perspective, as well as to cover all course results from the instructor's standpoint. The majority of teachers are not appropriately evaluating their courses' post-analysis approaches. The sample question (item) choose and the student answer are received from a technical exam or a mid-term MCQ question in order to evaluate the difficulty faced by the students and measure the quality of the questions (see table 6). The query is indicated by the item, and the values of ED, P, FV, and DI were cross-checked against the table 7 relationship.

TABLE 6
ITEM ANALYSIS FORMULAE FOR POST ANALYSIS PROCESS

Description	Formula	Interpretation
Difficulty Index (P)	P=((H+L)/N) x100	P <30% -Difficult, P=30-70% -Accepted P > 70%= Not accepted (easy)
Discriminative index (DI)	DI=(Ri-Rj)/N) x2	DI is –ve then DI=0-0.19 poor DI=02-0.29- acceptable DI >0.3 excellent
Facilitation value (FV)	FV=(Ri + Rj)/N	
Distractor effectiveness (ED)	ED= (Nl-Nu/N) x2	0-100% for MCQ’s

H-No. of students correctly answer in upper-grade group
L-No. of students correctly answer in lower grade group
N- Total number of two groups including non-responder
Ri- ∑ (No. of upper grade students x total marks obtained),
Rj- ∑ (No. of lower grade students x total marks obtained)
Nl, Nu- No. of lower group and upper group students.

TABLE 7
ITEM ANALYSIS FOR MID-TERM MCQ QUESTIONARIES

ITEM-1	A	B	C*	D
UPPER 27%	4	1	31	0
LOWER 27%	8	3	2	1
ED	0.2	0.133	-	0.066
P	53%	Since the P, DI, functionality is within limit so this question can be used without modification		
FV	0.53			
DI	0.4			
ITEM-5	A*	B	C	D
UPPER 27%	28	5	2	1
LOWER 27%	1	10	2	1
ED	-	0.33	0	0
P	2%	The P value less than 30% so the question is mis understand by the students and further modification in teaching method		

Similarly, the learning environment and infrastructure, as well as the design process, provide students with self-efficacy when confront with challenges in the model or solution proposed, authentic control in learning to provide novel solutions to societal problems, and the development of fluencies across all demonstration and review processes.

TABLE 8
RUBRICS FOR PROJECT-BASED LEARNING IN 18MT220 COURSE

S. No	Description	% of Marks
1	The selection of application related to problem statement	20%
2	Appropriate selection of motors and drivers	10%
3	Preparation of power point and chart materials to defend topic.	10%
4	Presentation and communication skills	20%
5	Proto type working model demo	40%

TABLE 9
RUBRICS FOR PROJECT-BASED LEARNING IN 18MT220 COURSE

Rubrics	*t*-value	*p*-value < .00001
1	-4.964	Satisfied
2	-6.187	Satisfied
3	-5.439	Satisfied
4	-7.098	Satisfied
5	-8.735	Satisfied

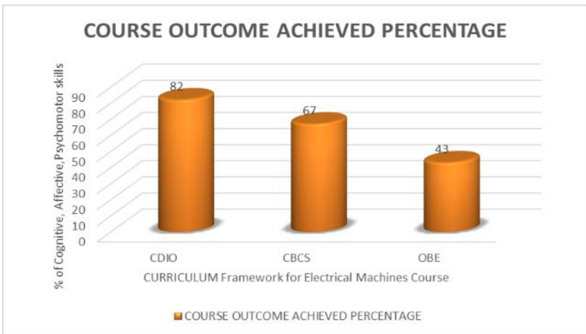

Fig 10: Comparison of curriculum course outcome in percentage.

The rubrics in table 8 are being used to evaluate the project-based learning activity results. The t-test hypothesis in table 9 demonstrates that the outcomes of PBL activity evaluation scores based on the rubrics in table 8 are compared between the CBCS and CDIO models. Out of five rubrics, the difference in performance is met, implying that CDIO implementation is more effective than OBE-CBCS in achieving project-based activity competencies. In each curriculum, the total comparison of course outcomes attained by each batch of students was shown in percentages. Empathy, attitude, and kinesthetic skills are given increased prominence in the CDIO framework, as seen in Figure 10.

VI. CONCLUSION

The curriculum structure in engineering courses is critical in creating adaptive competency. Students' interests in lifelong learning and adaptive design thinking are limited in the OBE and CBCS frameworks, but the emergence of CDIO pedagogical topology improves the learning ecology for students who see their engineering interest in lifelong learning and adaptive design thinking. By comparing CDIO curriculum to other framework-based techniques in electrical machine courses and comparing quality approaches, the article builds on the experiences of students and teachers. A capstone course is available to CBCS students at the end of their third year. As a result, students are left with a professional gap in which to develop self-directed learning topologies. The inclusion of Engineering exploration, lateral thinking, and design thinking courses in every semester beginning in first year, however, fosters a regulated learning ecosystem among students in the CDIO curriculum both inside and outside the classroom. The structured CDIO framework's success in engineering is due to the reconstruction and rethinking of course in each iteration. The CDIO framework provided practise to offset conceptual static structural knowledge and technique in design thinking for future generations. The author plans to continue the research by delving deeper into the study of Project-based learning and how it influences the affective and psychomotor domains through suitable evaluation in the future.

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