Engineering Design: A Sophomore Course for Undergraduates in Electrical Sciences

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Abstract— In this era of technological advances many engineering solutions have improved the quality of living for mankind. The focus has been on innovative designs in engineering education. This process has to be strengthened by engineering the design across all domains of engineering. Engineering Design as a course has been offered by universities restricting the curriculum to Mechanical Sciences, particularly in the domain of Mechanical and Industrial Production Engineering. The need to evolve pedagogy for Electrical Sciences students is the challenge which has been addressed through this paper. Curriculum design and delivery, course outcomes and attainments of an undergraduate course for Electrical Sciences is presented here. Pedagogical practices include domain specific case studies, skill development in laboratory, activity based learning, course projects and continuous evaluation. The implementation of course is analyzed with respect to attainment of the outcomes (ABET a-k). Validation of some of the course outcomes is demonstrated through sample case studies as applied to the specific domain of Electronics & Communication, Electrical & Electronics, and Instrumentation Technology (ECE, EEE, IT).

***Index Terms*—engineering design, electrical sciences, ABET outcomes, curriculum design.**

I. Introduction

Engineering Design has been a great tool to design solutions for engineering problems. The success of any design can now be guaranteed if a methodical approach is followed diligently. Many standard references on Engineering Design [1] have been instrumental in documenting and proposing the methodologies for design. The research trend in Engineering Design is multi-dimensional and many approaches to optimizing and improving the success rate of designs are presented in [2] and [3]. Harnessing creativity in Engineering Design is addressed in [4] through integration of engineering design and cognitive psychology literature.

In higher education scenario, Engineering Design as a course has been delivered at the formative years of an engineering student. In many universities the course has been provided primarily to Mechanical Sciences students. Accordingly the standard reference books focus on case studies for these domains of engineering while explaining the concepts of Engineering Design. In the ever increasing multidisciplinary nature of real world engineering problems it is imperative that electrical engineering students are also engaged in Engineering Design early in their education.

An effort has been made in our institute to imbibe the design process among Electrical Sciences students. This paper presents the challenges faced in design and implementation of Engineering Design course for students at the fourth semester level, in the engineering disciplines of ECE, EEE, and IT.

The distribution of sections in the rest of the paper is: Section II frames the expected outcomes of the course based on requirements of the skill sets of an undergraduate student. Section III describes the process of curriculum design. In Section IV we present the curriculum delivery using domain specific case studies in ECE, EEE and IT engineering. Finally in Section V we demonstrate the assessment methodology with corresponding outcomes (ABET a-k).

II. Course Outcomes

Real world problems are ill structured and open ended in nature. The domain of the problem will be ambiguous and will not have a unique solution. The main objective of Engineering Design course is to make students familiar with the design process which will aid in solving real world engineering problems. Emphasis is laid on active learning through interactive lecture sessions, laboratory & field assignments, and course projects. The course outcomes are listed in Table I.

The course outcomes are mapped to the ABET outcomes and are focused at different levels of attainment as low, medium and high (L, M, and H). This mapping is demonstrated in Table II. The attainments of these outcomes are measured using the methodology presented in Section V.

TABLE I. Engineering Design Course Outcomes

CO	Course Outcomes
1.	Demonstrate working knowledge of engineering design process through the following: a. Identifying the basic steps in the design process b. Applying those basic steps to simple designs c. Completing a successful team design project
2.	Demonstrate successful teamwork
3.	Analyze the designs for manufacturability
4.	Evaluate the performance of the design
5.	Build computer models and/or prototypes
6.	Prepare and present an oral and written engineering project report

Engineering design process requires early intervention in the engineering curriculum, so as to enable the student to apply the design process in problem solving during higher semesters. While offering the course early, care has to be taken to ensure prerequisite concepts of circuit analysis and systems. This is essential, since system integration involves identifying and designing the basic building blocks.

TABLE II. MAPPING OF CO WITH ABET 3A TO 3K

CO	a	b	c	d	e	f	g	h	i	j	k
1.	M		H		L	H	H				
2.							H				
3.	M										M
4.	M										M
5.		H	H								H
6.						H	H				

III. CURRICULUM DESIGN

Engineering design as a course is being delivered in our institute for mechanical sciences since four years. The challenge is to adopt similar pedagogy to Electrical Sciences. The curriculum design process commenced with the formation of a core multidisciplinary team of faculty members. The Mechanical Sciences domain experts mentored the faculty from Electrical Sciences over a period of six months prior to the course launch. Regular brainstorming sessions over appropriate case studies / examples to convey the concepts of Engineering Design were facilitated. This led to an effective pedagogy to convey engineering design process through domain specific approach. The curriculum is structured into an integrated theory, laboratory and course project module. Ample opportunity for creativity and innovation in teaching-learning process is provided to the faculty and students. The theory content is largely adopted from [1] and is listed in Table III. The challenge is to innovate in the domain specific case studies for each of the design processes. Some of the innovations in pedagogical practices are presented in Section IV.

TABLE III. ENGINEERING DESIGN CURRICULUM

#	Topic	Hours
1.	Engineering Design & Design Process	4
2.	Definition of the Problem	3
3.	Functions & Requirements	3
4.	Generating & Evaluating Design Alternatives	4
5.	Design Modeling, Analysis & Optimization	4
6.	Communicating the Design	2
7.	Designing for X	3
8.	Ethics in Design	2

A laboratory module is also developed to address the skill-set requirements for Engineering Design. The proposed outcomes of the laboratory are listed in Table IV.

TABLE IV. ENGINEERING DESIGN LABORATORY COURSE OUTCOMES

CO	Course Outcomes
1.	Be proficient in usage of eCAD tools with a perspective of Engineering Design
2.	Design components and integrate into a system
3.	Design components with constraints specified by design engineers from other disciplines
4.	Prototype the design on a PCB through the processes of Image transfer, Etching, Drilling, Component mounting and Soldering

The list of experiments is designed beginning with the study/observation of a complex printed circuit board and culminating in a design and implementation for a chosen need, as shown in Table V.

TABLE V. ENGINEERING DESIGN LABORATORY CURRICULUM

#	Laboratory Description	Hours
Category: Exercises		
1.	Study of PCB, survey and list observations.	1
2.	Demonstration of AutoTRAX eCAD tool	0.5
3.	Exploration of AutoTRAX eCAD tool through demonstration of simple digital and analog circuits	1.5
Category: Structured Enquiry		
4.	Building an application using power supply and some key components A. Power supply design. (1 hr) B. Signal generator / other application (1hr) C. Placement and PCB Layout (2 hrs) D. PCB implementation (2 hrs) E. PCB assembly, soldering and testing (4 hrs) F. Presentation & Demonstration (2 hrs)	6

Engineering Design process is supplemented with usage of open source tools for project management, design for quality and other tasks. The concepts of Engineering Design are delivered through active learning sessions and field assignments as described in the next section.

IV. COURSE DELIVERY

Engineering Design is offered as a 4-credit course to fourth semester students of ECE, EE and IT. The challenge is to deliver the course to over 350 students across 6 divisions in 3 departments. The resources required for faculty and laboratory are planned in advance. The faculties are mentored regularly by Engineering Design experts from Mechanical Sciences departments.

Engineering design manifests as a team activity. Accordingly the course delivery and attainment is focused towards team dynamics. Each class is divided into 20-25 teams of 3-4 members each. Every member has to effectively work in the roles assigned and demonstrate soft skills, technical skills and leadership qualities. The main job of faculty during the course is to facilitate this process and provide guidance on the resources.

A dedicated course web page is used to communicate with the students for course related announcements, deadlines and other course material. The distribution of the course delivery is: 25 hours for interactive lecture sessions, 25 hours for active learning through innovative tasks, and an additional 18 hours spread across 9 laboratory sessions for skill development as listed in Table V. The application of design concepts through course projects is a major component of Engineering Design, and regular guidance and assessment is carried out at regular intervals during the semester. A few case studies for the various pedagogical practices are presented in the next subsections.

A. Design process as a process of questioning: Case study

The designer-client-user triangle concept is experienced through an innovative team activity. Each team is given a need statement and a single page document as shown in Fig., 1. Each student takes up the role of a designer, user or client, and a thorough process of questioning is documented in a graphical format. The analysis of the needs and requirements are elaborated by the user, while the client and designers draw the boundaries for design in terms of constraints.

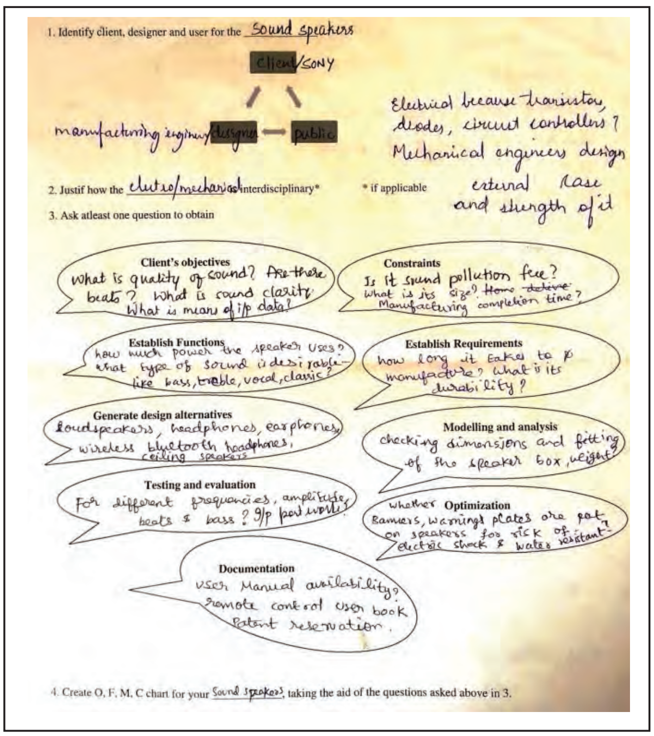

Fig. 1. Case study of designer-client-user traingle activity

Some of the outcomes of this group activity are: users' needs can be classified as demands and wishes, client's problem statements are vague and need clarity from user, designer provides the feasibility and provides a value proposition to the client.

B. Design modeling, analysis and optimization: Case study

The domain specific case study chosen for the topic on design modeling, analysis and optimization is a half-wave rectifier. The design process is carried out in a sequence of steps, starting from the need analysis, technical specifications, proposed circuit diagram, mathematical modeling, simulation, analysis and optimization as shown in Fig. 2.

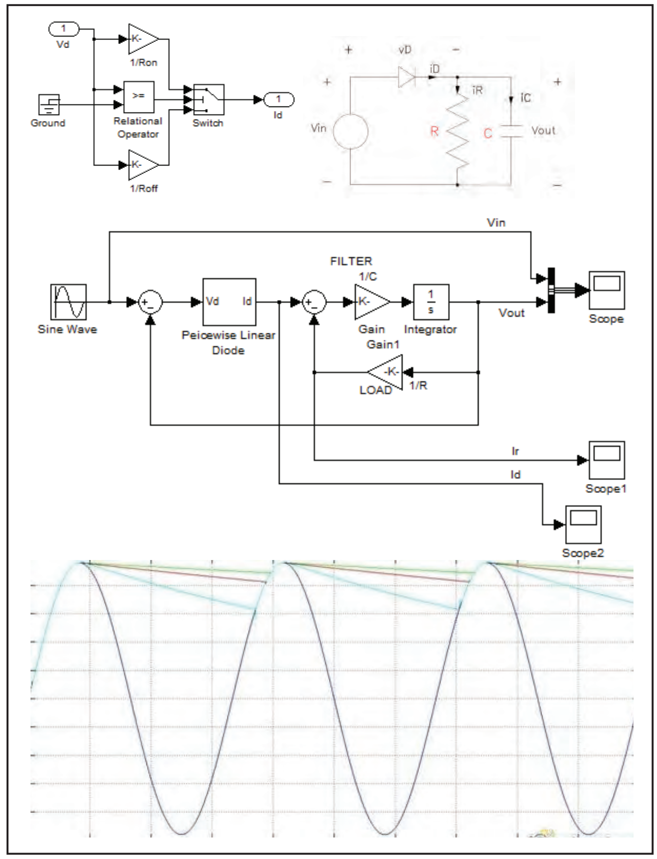

Fig. 2. Case study of design modeling, analysis and optimization

The domain specific case studies are developed based on the understanding of requirements, and adapting the pedagogy from standard references of mechanical sciences. The entire process is mentored by expert faculty, and innovative case studies are encouraged.

C. Course projects: Case study

The need statement for course projects is predefined at the beginning of the course. Five statements are identified for three departments after rigorous brainstorming with mentors. The need statement is chosen keeping in mind the importance of real world problems being ill-structured and open ended. A total of 75 teams plan and execute 5 different projects across the college following the methodology of engineering design. Few of the need statements are listed here.

1) Design a suitable cost effective electronic device for automating the forced water pumping process at domestic homes. The device should turn on the electric motor (single phase induction motor) whenever the overhead tank is empty and stop the motor when the overhead tank is critically filled based on availability of water in sump tank. The controller should come out as a portable product which is easy to use by common layman.

2) Design a safe and intelligent locker for home/office applications which can detect unlock patterns chosen by you. The patterns could be keypad, sound, image etc. The device has to be easy to operate and equipped with appropriate actuators to open/close the locker. The device should consume less power and work on battery cells for longer periods for one charge. Teams are free to use any form of mechanism to operate the locker.

3) Design smart and safe electronic pest control system for domestic or agricultural applications which can control chosen pest. The device should consume less power and work on battery cells for longer periods for one charge. Teams are free to use any form of mechanism for pest control design.

The boundaries for design are set taking into consideration the limited prerequisites the students possess. To prepare students for industry, sufficient experience in exploring possible alternative solutions for solving real world problems is provided.

D. Best Practices: Case studies

1) Market Survey:

Some of the best practices identified from across the spectrum of 75 teams are presented here. Fig. 3 shows the survey of relevant data for safe lockers. The data points to the fact that domestic burglary is increasing at a faster rate than other theft. Accordingly the survey indicates the user market for a smart and safe locker.

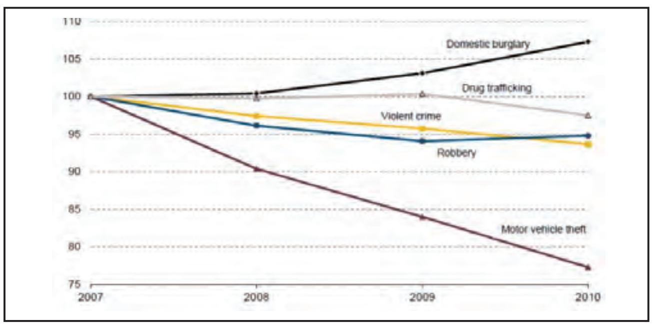

Fig. 3. Data collection and analysis for safe locker

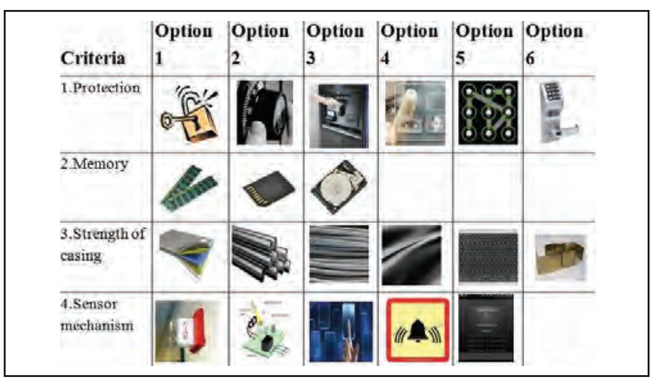

Fig. 4. Morphological chart depicting alternate solutions for safe locker

2) Concept Generation:

Fig. 4 shows the alternate solution exploration using morphological chart. Here the various methods of security are explored along with all possible functions and sub-functions listing, each with multiple concepts.

3) Concept Evaluation:

Fig. 5 depicts the scoring methodology to choose an appropriate solution based on the need analysis. Every team lists the priorities and weightage that has to be accorded to the demands/wishes of the user. Based on this criteria the concepts are ranked, and the concept graph which scores the highest is choosen for preliminary design in the next stage.

SELECTION CRITERIA	WEIGHTAGE	COMBINATIONAL LOCK		Code lock		PATTERN		BIOMETRIC	
		Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Safety	40%	2	0.8	3	1.2	4	1.6	5	2
Ease of use	20%	4	0.8	3	0.6	4	0.8	3	0.6
Durability	15%	4	0.6	3	0.45	2	0.3	3	0.45
Power consumption	5%	5	0.25	3	0.15	2	0.10	1	0.05
Cost	20%	3	0.6	3	0.6	4	0.8	5	1
Total score	100%	3.05		3		3.6		3.56	
Rank		3rd		4th		1st		2nd	

Fig. 5. Concept scoring and selection methodology

4) Proof of concept / Simulation:

Fig. 6 demonstrates the functional simulation using a microcontroller. The interface for the user to enter an unlock pattern is demonstrated here. The lockin/unlocking mechanism of the locker is also demonstrated through a motor driven by the microcontroller.

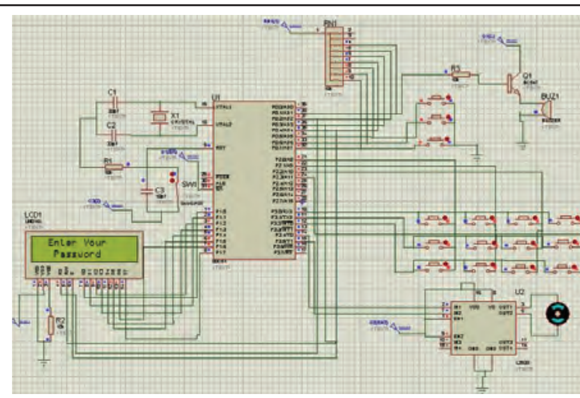

Fig. 6. Functional simulation of the security system in a safe locker

Some of the teams explored into other domains of engineering by using open source tools for 3D rendering of locker casing designs. Though not mandated, the students were encourged to innovate and learn new tools to harness their potential. The 3D rendering of a safe locker casing is depicted in Fig. 7.

Apart from few of the demonstrations depicted from Fig. 3 to Fig. 7, the engineering design process included patent search, market survey, need analysis, identifying objectives-constraints-functions-means (OCFM) form need listing, objectives tree, arriving at specifications, redefining the problem statement, functional analysis, conceptualization, preliminary design, detailed design, and prototype/mockup of the product. The culmination of the course is through an assessment of design and hardware implementation of the chosen application.

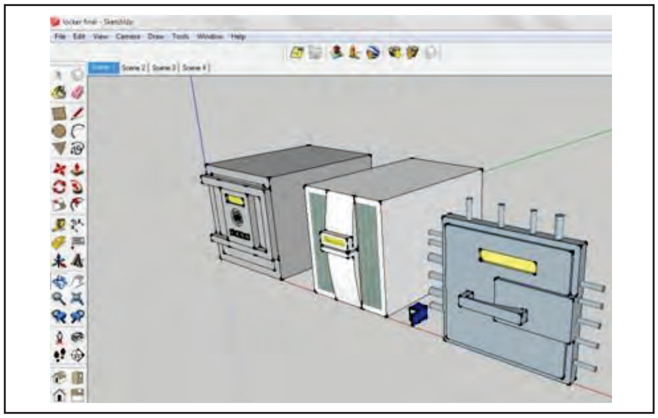

Fig. 7. 3D rendering of the design for safe locker

V. Course Assessment

Engineering design course is assessed by carefully designed assessment rubrics. The assessment plan for course projects is provided in Table VI. 20% of the evaluation is for mid semester tests, 20% for the course project, and 10% for laboratory assignments. The remaining 50% is evaluated in end semester exam.

TABLE VI. COURSE PROJECT ASSESSMENT PLAN

#	Task	Marks
1.	Perform need and market analysis & derive the requirements, WBS & Gantt chart	3
2.	Functional analysis and product specifications	3
3.	Conceptualization	3
4.	Evaluating alternatives	3
5.	Detailed analysis and simulations	3
6.	Prototype development	2
7.	Final presentation and report submission	3

To ensure uniformity in assessment across 75 teams in 3 departments, carefully drafted rubrics were used. A sample set of rubric is depicted in Table VII.

TABLE VII. COURSE PROJECT RUBRICS: SAMPLE SET

Best (3)	Average (2)	Poor (1)
Planning : i. Preparing Gantt chart ii. Level of creativity in the proposed plan of execution		
Identifying all the tasks & processes	Not elaborate enough	No planning
Need Analysis: i. Diversified Professional customer feedback form ii. Listing maximum number of attributes taking aid of customer feedback and literature survey		
>10 forms + >20 attributes	8-10 forms + 15-20 attributes	<10 forms + <15 attributes
Conceptualization: i. Arriving at more meaningful concepts taking aid of functional analysis performed		

Best (3)	Average (2)	Poor (1)
Planning : i. Preparing Gantt chart ii. Level of creativity in the proposed plan of execution		
ii. Evaluation of concepts using matrix methods and hence arriving at final design		
>5 Concepts to one Best design	4-5 Concepts to one Best design	<4 Concepts to one best design

All students are assessed in three reviews. In each review the teams are evaluated for different steps in engineering design process. The team dynamics is considered to be one of the important assessment factors in all reviews. To evaluate the participation of each student, work breakdown structure (WBS) is monitored throughout the course. The teams document the progress by way of intermediate results and pitfalls encountered during design in a bluebook. After the completion of course project, the teams submit a technical report along with an oral and visual presentation.

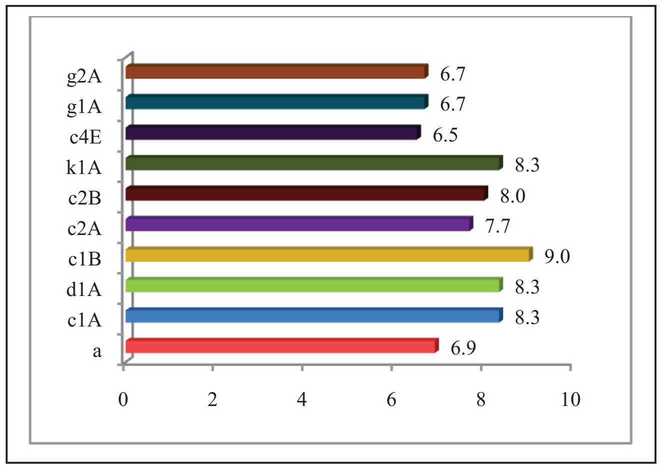

Fig. 8. Attainment of course outcomes through CIE and SEE

The attainment of course outcomes evaluated in three CIE reviews and a semster end examination are presented in Fig. 8. The figure represents the Performance Indicators(PI) used to measure the level of attainment of ABET outcomes 3a-3k. Table VIII lists the PIs as defined by ECE department.

TABLE VIII. PERFORMANCE INDICATORS USED FOR MEASURING COs

Code	Performance Indicator
c1A	Ability to identify the requirements of a given engineering problem.
d1A	Ability to define roles and responsibilities of team members
c1B	Ability to use engineering fundamentals to establish the design specifications.
c2A	Ability to explore design alternatives.
c2B	Ability to evaluate feasibility of alternatives and propose appropriate solution by considering the constraints.
k1A	Ability to use EDA tools for modeling and simulation
c4E	Ability to build the prototype and validate the results.
g1A	Ability to write clear and well organized project reports.
g2A	Ability to prepare presentation using visual aids.

The outcome ‘a’ is ‘ability to apply knowledge of mathematics, science and engineering to model and analyze VLSI, Embedded and Communication systems’.

It is observed from Fig. 8 that PIs c1A, c1B, c2B, d1A and k1A are above the average target of 8.0. The attainment in c4E is the least at 6.5, which indicates the lack of opportunities provided for the teams to build prototypes. The PIs g1A and g2A which relate to technical report writing are also observed to be well below the set targets. The results also provide insights into the reasons for good/poor performance in the individual questions in SEE as depicted by outcome 3a being 6.9 on a scale of 10.

VI. Continuous Improvement

Evaluation of a student at the end of a course is an indication of the strengths and weakness of a teaching-learning process. The consistency in assessment methodology and the perception of attainment by the student is an indicator of success of evaluation. A method of identifying the effectiveness of the course content, delivery and learning is through a course-end feedback by the students. The results of this feedback are summarized in Fig. 9. The questionnaire list consisted of the outcomes as listed in Table IX.

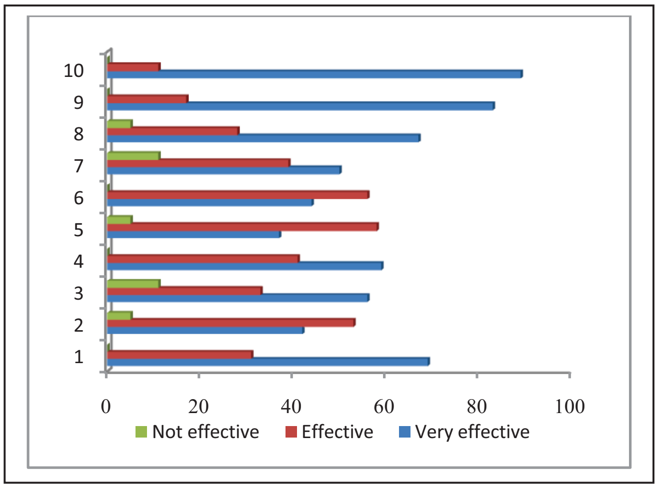

Fig. 9. Feedback summary of Engineering Design course by students

TABLE IX. Questionnaire for student feedback

Q.No.	Particulars
1.	How effective was engineering design course in understanding design process to attend engineering problems?
2.	How effective was course to make you design and conduct experiments?
3.	How effective was course to make you design a system or component in a system?
4.	How effective was course in conveying engineering ethics?
5.	How effective was the course in improving your technical communication skills?
6.	How effective was the course in strengthening your skills in using modern engineering tools?
7.	How helpful is the design process in carrying out engineering projects?
8.	Was the lab module effective in improving your PCB design skills?
9.	Did the course encourage you to work in interdisciplinary branches of engineering?
10.	Would engineering education be incomplete without this course?

The consistency can be observed in the ineffectiveness of imparting technical report and communication skills, both in Q5 (least among very effective @ 37%) and in PIs: g1A and g2A (6.7 out of 10). Improving the technical report writing and communication skills shall be a key area for targeting improvement in the next cycle of course delivery.

Another important observation in the student feedback is despite the lesser level of effectiveness in some areas, the students overwhelmingly agree that Engineering Education is incomplete without a course on Engineering Design.

After having completed this course the students have become proficient in understanding and solving real world engineering problems, using modern engineering tools. The course also has improved the skills of students in technical communication, but there is scope for improvement.

Most of the teams followed the design procedure diligently though they did not get the final output. Some teams were seen skipping intermediate steps and jumping to the solution for the defined problem without proper evaluation of alternatives and need mapped objectives.

VII. Conclusion

This paper presented the design, delivery and assessment of a four credit course Engineering Design for Electrical Sciences students at 4th Semester. The course filled the gap in understanding of the real world problems by students, and also provided a systematic approach to design. The learning is to be applied during higher semesters for mini-projects and capstone projects.

The evaluation yielded a positive outcome on almost all aspects of engineering design, while indicating the challenges in technical communication, and laboratory module. In the upcoming cycle of Engineering Design, we intend to provide need statements with a social and ethical context, so as to challenge both students and faculty.

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