An Experience of Teaching Engineering Design for Freshman Students

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Abstract:
In recent years design thinking has taken center stage in the engineering curriculum. The driving force being the society and industries who need graduate engineers who can design, innovative, and creative products to help solve the real-world problems. The current paper discusses the experiences of a systematic approach in defining, teaching, and assessing the engineering design process to freshman engineering students at KLE Technological University (KLETU). The paper begins by defining 'design thinking' followed by briefly reviewing the role of engineering design and its importance in the engineering curriculum. Design is hard to learn but hardest to teach. Efforts have been made, in this work, to bring in the perspective of the pedagogy of activity-based teaching and its challenges and opportunities in teaching engineering design process at the freshman engineering level. This pedagogical approach, for freshman level, resulted in enhanced students learning.

Keywords: Design, Freshman Engineering, Activity, Learning

I. Introduction

Design is at the core of any engineering discipline and is the heart of engineering practice. Engineering experts consider design being synonymous with engineering (Mourtos NJ et al., 2012). Presently in most of the engineering institutes, designing is taught at the sophomore or senior semesters and is finally realized in the form of course project or capstone project. Bringing in design thinking at freshman level will not only enhance student's ability to think creatively and bringing innovative alternatives but also helps the student to put the entire engineering curriculum into perspective.

To describe the background of introducing design thinking at freshman level in KLETU goes back to 2015-16 when institute joined hands with Virginia Technological University (VT), USA. This collaboration helped in understanding and adapted engineering exploration course, which was earlier taught at VT for freshman engineering students(McDonald WM et al.). Globally, many efforts have been made even before to teach engineering design course at different levels in engineering institutes. Which are mostly project-based learning approach is followed (Ambrose SA et al., & Genco N, Hölttä-Otto K, 2012). The work presented in this paper is first of its kind in the Indian context, where activity-based learning pedagogy was followed to infuse design thinking. Here the authors have given their experiences in defining, designing, delivering, and assessing engineering design content for first-year students in the course Engineering Exploration. The data presented here tracks pedagogical efforts for the academic year 2015-16 and 2016-17 (odd & even semester).

The study conducted with the following research question:

How do the design process and pedagogy influence students' ability in problem formulation and solution methodology?

II. Background literature survey

Julie D. Burton & Daniel M. White, 1999 reviews eight methods for teaching design for freshman engineering students which were the outcome of survey of about 43 ABET-accredited Engineering Schools/ Universities across USA. The methodologies include Reverse Engineering, Creating Something Useful, Full-Scale Project, Small Scale Projects, Case Studies, Competitions, Non-Profit Project and Re-design of a Local Project.

Payton L. N, 2005 illustrates a general approach of first-year students working in multidisciplinary teams in building production aircraft. Designing, production, and testing were the principal stages in building a production aircraft which had to meet statistical quality control performance parameters set by the customers.

Kinda Khalaf et al., 2013 discuss a design-and-build course at the freshman level for early engineering design education. The course adopts project-based learning (PBL) pedagogy and prescriptive design cycle as a mode of design teaching.

Sanjay E. et al., 2015 reports curriculum design and delivery, course outcomes, and attainments of an undergraduate course for electric sciences. They adopted domain-specific case studies, laboratory exercises in laboratory, activity-based learning, and course projects as pedagogical methods for teaching.

Arun Y Patil et al., 2016 present their efforts in teaching design for post-graduate students in Integrated Product Design (IPD) course. They relied on laboratory sessions to impart design tools viz., Industrial Design Sketching, Six sigma techniques with the aid of MINITAB software and course project as an outcome.

Many efforts have been made in teaching engineering design at freshman engineering as well at higher levels. The major methodology followed is through full-scale projects or activities. A new methodology where integrating activity-based learning followed by a full-scale project can be done to reinforce classroom learnings.

III. Thinking 'Design'

Design problems vary from those requiring relatively routine solutions based on generally well-developed knowledge and existing systems to those demanding highly innovative solutions.

To begin, in solving any design problem is to acknowledge that there exists a problem. The first step in any design effort resulting in a better product/process is to identify and understand the end-user needs. Design always begins with identifying undesirable and desirable situations of customer needs and ends with devising a plan which tries to fulfill the needs of the end-user

The design is a blueprint- a plan for change from undesirable to desirable situation. Again, a matter of perception- whose, where, and when- plays a crucial role in identifying the undesirable situation. In a nutshell, designing is all about problem understanding and problem-solving.

The next question would be what design means in the context of engineering? Hubka V and Eder WE, 2003, describe the design in the context of engineering. The authors state that 'Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify designs for devices, systems, or processes... achieve client's objectives and user's needs while satisfying a specified set of constraints'. This definition sets the direction for the course. This definition describes the design as a thoughtful process. Wherein a designer has to generate multiple solutions, evaluate the alternatives for the best solution against the identified constraints, and specified technical values to achieve the user's needs ultimately.

IV. Challenges

One cannot be a good designer if he/she does not wet one's feet. Teaching, as well as learning design for a novice, is a challenging one. Authors have observed several challenges in teaching this course to first-year students:

- ⊕ Handling mass classes associating with faculty with different discipline background.
- ⊕ In teaching design, both theory and practice need to be involved. Hubka and Eder, 2003 have identified four types of knowledge required in a design process, namely object knowledge, theory knowledge, practice knowledge, and process knowledge.
- ⊕ One more vital point to be considered is the competency of teacher teaching engineering design.
- ⊕ Designers, at times, work alone within a discipline, e.g., Mechanical, Electrical or Computers or in a combination of them. At some other times, they must work in a team. Designing may need human conflict resolution, overcoming 'group think,' detecting, and avoiding errors. (Hubka V and Eder WE, 2003). Developing a curriculum for engineering design has to consider these aspects. Students have to be given a flavor of these components so that they can appreciate the importance of the multi-disciplinary nature of engineering design and teamwork in such a scenario.

V. Methodology

The following sections discuss the course structure of course "Engineering exploration" followed by Engineering design module content, its delivery, and assessment. This section also includes various activities that were part of the module.

A. Course Design

The course Engineering Exploration had a total of nine modules, and Basics of engineering design & multidisciplinary nature of engineering design is one among them. The module covered 12 hours of the whole course. Table 1 shows course content which contains nine modules, and the module of the current paper appears at serial number

5 - Basics of engineering design and Multidisciplinary nature of it.

Table 1. Course Content

Chapter #	Name	Sessions (In hrs.)
1	Introduction to Engineering and Engineering study	3
2	Role of Analysis in Engineering	3
3	Analysis Methodology	3
4	Data Analysis and Graphing	6
5	Basics of Engineering Design	6
	Multi-disciplinary nature of Engineering design	6
6	Project Management	3
7	Sustainability in Engineering	3
8	Ethics	3
9	Course Project focusing on Sustainability in Engineering	12

B. Module Content and Delivery

The following goals were considered to design the content for the engineering design module.

- Explain the engineering design process
- Identification & Prioritization of Design problem's objectives
- Know-How- Identifying sub-systems and functions
- Identify multi-disciplinary facet of design
- Develop multiple solutions/concepts
- Decision making in design
- Build proposed mechanical/mechatronic system

Design problems are always ill-structured and non-formulaic (Stojcevski A, 2014). The client/customer, when poses his/her needs to the design engineer, will be verbose and descriptive. This descriptive problem lacks technical detail from which the designer has to define the engineering problem statement. This phase is very critical as this drives further design efforts.

Designing is intricate in many respects. The usual first difficulty is starting to design, where and how to begin, overcoming a natural fear of reaching into the unknown (Hubka V and Eder WE, 2003). This definition necessitates a structured design process which a novice designer can follow to solve problems. The structure of the engineering design varies slightly from one model to another or one organization to the other. A simple 5 step design process, as shown in Figure 1, was adopted. This simple process eased students' learnability and applied it to the given real-world problem.

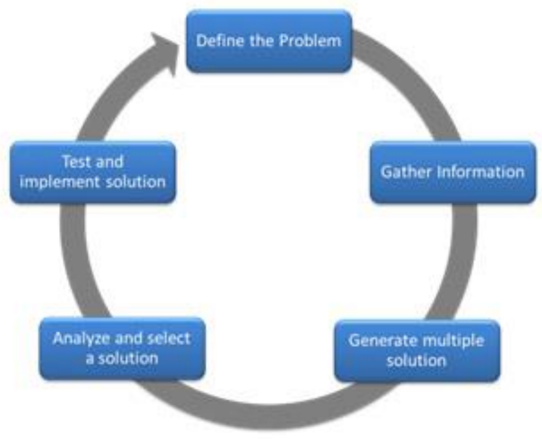

FIGURE 1: Design Process

A group activity was conducted to convey the design process. It was followed by one more reinforcement activity to enrich students' understanding of the design process, and it is utility in solving real-world design problems.
Numerous activities were conducted to address all the identified module objectives and corresponding outcomes, as listed in Table 2.

Table 2. Activities and expected outcomes

Activity #	Activity	Outcome
1	Building a structural block	Demonstrate need of structured design process
2	Catapult design & build– mathematical treatment to the design problem	Apply the engineering design process
3	Power supply design	Identify the multidisciplinary nature of engineering design
4	Pair-wise Comparison Chart method	Identify design objectives and prioritization
5	Robot building	Building a mechatronic system
6	Know-How: Reverse engineering activity	Identify functional blocks in a system
7	Identify functional blocks in a system Electronic system & gearbox	Able to generate multiple solutions for the defined problem statement and select - the better one.
8	Safe landing pad Activity	Students would carry out the activity applying all the learning of the Engineering Design Module

The idea was to give incremental learning of the design concepts to students as they are a novice to the engineering problem solving, which are mostly real-world issues. To exemplify, activity 1 had the objective of building a structural block using fragile items, and successful design has to carry the highest weight. The students had to follow a layman approach since no discussion on the philosophy of engineering design, or any techniques of developing alternative solutions was done. As the module progressed, students introduced to various methods of identifying constraints, design objectives/client needs. Discussed a methodology to develop alternative concepts and evaluating them for best design against prioritized objectives. Students exposed to other activities with increased scope for applying design learning.

Many times studying the existing system can give better cues to enhance the system or create a new design entirely. Reverse engineering activity prompts novice designers (students) to think about design alternatives.

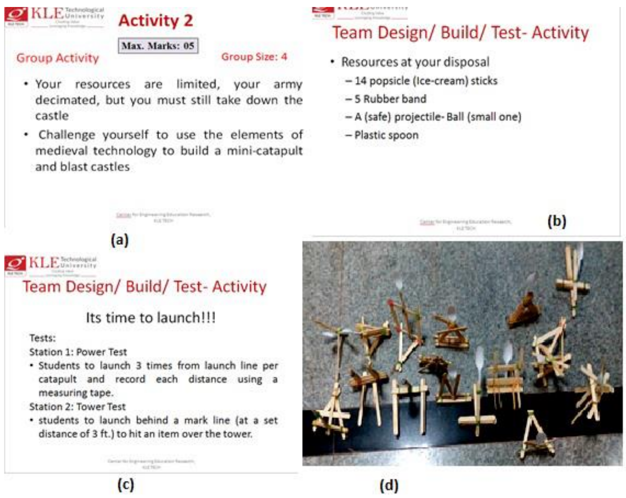

FIGURE 2: (a-c) Description of Catapult design activity; (d) various models built by students

A sample case of design activity presented in Figure 2(a-d). Student groups were given with a description of the activity from which group had to formulate their definition of the problem and relevant objectives, constraints to solve the problem. While applying the learning of the design module, the group had to come up with solution alternatives. Evaluate them for a better solution against objectives/constrains and finally build and test the design artifact for given test condition.

C. Rubrics and Evaluation

Students were assessed both in an individual and in a group. The quiz conducted at an individual level and activities for group assessment. Rubrics for various activities shown in Table 3 and Table 4 (Appendix-A). The rubrics prepared with an eye on the students' adherence to the design process. The weight was fixed based on both teachers experience of handling design course at the sophomore level and importance of a particular step in the process. The rubrics also indicate the associated Performance Indicators' (PI's) addressed through design activities. The PI's derived from Program Outcomes (PO's) adapted at KLETU, which are equivalent to Graduate attributes of ABET. In this work PO- 3 is addressed. PO-3 corresponds to the *Design/development of solutions. Described as Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for public health and safety, and cultural, societal, and environmental considerations*."

Multiple choice quizzes were conducted to assess the multidisciplinary facet of engineering design. A representative set of questionnaires listed in Table 5.

Table 5 Sample Quiz questionnaires

• The engineering analysis process involves
• Do engineers always to be blamed for failure that occurs?
• Rectification is the conversion of_____
• In the given circuit(in Engineering Exploration), Mention the value of Resistor "R"
• Calculate N2 for the given data of a Gear. N1=5000,T1=20,T2=50

VI. Results and Discussion

A mandatory course, "Engineering Exploration" introduces an engineering design process to freshman students by activity-based learning pedagogy. Authors have taught this course since its inception at the institute and have the experience of teaching large classes of Engineering design courses at a sophomore level over the years in their respective disciplines. This experience helped them to counter many challenges listed in this paper.

Students admitted to engineering courses after their pre-university science studies face difficulty when posed with real-world design problems. Their previous curriculum did not give them the chance to address any real-world scenarios at least from the designer's point of view. With this background, students were introduced to do the designing task. Activity-based learning with simple design process gave students an upper-hand to solve real-world problems. Here, as students evaluated the given customer need statement, analyzed it to understand the scenario using learned techniques, develop multiple alternative solutions, and propose best engineering solutions to it. This pedagogical approach of activity-based learning with structured design process enhanced students learning. This claim is reinforced by their pre and post responses, as shown in Figure 3 and the outcome of the course project.

Table 6 Questionnaire for Pre and Post-test

1.	Knowledge about Engineering Design Process
2.	Knowledge of Analysis in Engineering design
3.	Multidisciplinary aspects of Engineering Design and its importance
4.	Mechatronics system and its components
5.	Conversion from AC to DC Power
6.	Design of DC regulated the power supply
7.	Usage of Digital multi-meter and Breadboard operation
8.	Design of mechatronics system that converts electrical into mechanical energy
9.	Know-how of Reverse Engineering

10.	Types of drives and gears
11.	Assembly and Disassembly of a gearbox
12.	The building of mechatronics system like automatic mobile robot

Table 6 lists questionnaires for Pre and Post-tests. The responses ordered categorical (ordinal) data. The mode calculated for each response, for both pre and post-tests responses, and graphs are plotted.

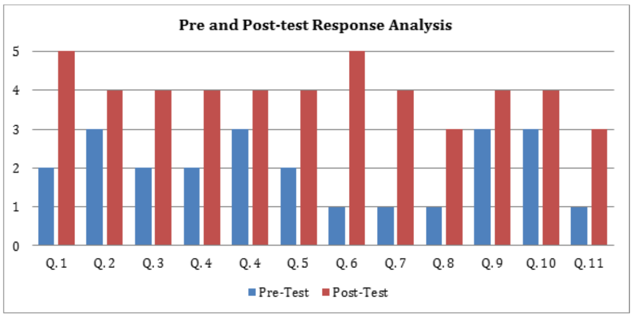

FIGURE 3: Pre and Post-test response

VII. Conclusions and Future Work

Globally many efforts have been made to teach designers. Teaching design at academia, at different levels, has always been the focus as the design is at the core of engineering discipline. Here in this manuscript, the authors experience in design, delivery, and assessment of engineering design for first-year students has been presented. The content was a module of a mandatory course "Engineering Exploration." This is one kind of study where an active and collaborative learning ecosystem can be created, and students are made to learn design. This methodology also eases the teacher in teaching design philosophy at an early stage of engineering studies. Pre and Post-tests also reinforce this claim as more students indicated enhanced learning. Results from this inference of students' feedback have been used to refine the content of future delivery of the same course and other dependent courses. Activity based-learning with structured design process pedagogy was used in infusing design thinking. Many challenges in developing and delivering the content have been identified and presented. Different activities and their respective outcomes are exemplified.

In this paper, authors have shared their experience of designing and delivering engineering design as a module for freshman engineers at KLETU. This course is being used as starting-point in enhancing the Engineering Design Curriculum at subsequent senior semesters. This would be achieved by having a collective content across departments like Electronics & Communication Engineering, Mechanical Engineering, Computer Science Engineering, and Automation & Robotics, etc. The present content is also currently undergoing various structural changes in subsequent iteration with faculty experience and student's feedback (course feedback and focus group discussion) gained in the first and second iteration.

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Appendix-A

Table 3. Rubrics for Catapult Design Activity

Assessment Parameters	**Weightage**	**Excellent (10 marks)**	**Good (6-8 marks)**	**Needs Improvement (2-4 marks)**	**PI's**
Understand the need and Gathering Information	20%	The team is able to clearly state the aim of the problem and list the constraints	The team is able to state the aim of the problem but has no clarity about the constraints	The team is able to develop an understanding of the problem with the instructor's help	3.1.6
Generate multiple solutions and select the best	40%	The team is able to generate at least two solutions – with concept ketches/ descriptions and is able to choose the best design after analysis of the alternatives	The team is able to generate at least two alternative solutions- with sketch/descriptions but is unable to do right kind of parameters for analysis	The team is able to complete the task with the instructor's help	3.2.1
Build the model as per the design and Test it	40%	The team is able to build the model as per the proposed plan/design and is able to test and clearly state the shortcomings in the design for further improvement	The team is able to build the model as per the proposed plan/design and is able to test and but is unable to state the shortcomings in the design for further improvement clearly	The team is able to complete the task with the instructor's help	3.2.2

Table 4. Rubrics for Landing Pad Design Activity

Assessment Parameters	**Weightage**	**Excellent (10 marks)**	**Good (6-8 marks)**	**Needs Improvement (2-4 marks)**	**PI's**
Understand the need and Gather Information	10%	The team can state the aim of the problem clearly and lists all the constraints	The team can state the aim of the problem but has no clarity about the constraints	The team can develop an understanding of the problem with the instructor's help	3.1.6
Generate multiple solutions	30%	The team can generate at least four solutions – with concept sketches/ descriptions	The team can generate at least two alternative solutions with sketch/ descriptions	The team can complete the task with the instructor's help	3.2.1
Analyze and select the solution	10%	Able to list relevant design criteria and can choose the best design after analyzing the alternatives	The team can select relevant design criteria but unable to select the best solution after analyzing the alternatives	The team can complete the task with the instructor's help	3.3.1
Build model as per design	40%	The team can build the model as per the proposed concept/solution.		The team can complete the task with the instructor's help	3.2.2
Test and identify short comes/evaluate for failures		Test and clearly state the shortcomings in the design for further improvement.		Tests but unable to analyze and clearly state the shortcomings in the design for further improvement	3.4.1