Multidisciplinary Approach to Product Design and Realization

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Abstract This paper discusses development of project-based ‘product design and realization’ course for undergraduate students. The course offered at an early stage of the curriculum is aimed at providing engineering design and product realization skills to the students. Creating an appropriate learning experience in product design is challenging owing to its multidisciplinary nature. An innovative multidisciplinary design-to-realization approach is adopted in this course and student teams are required to design and build working prototypes for predefined products. This course brings a new perspective to the multidisciplinary approach to teaching product design. Introduction of project-based design experience at an early level provides students with an opportunity to develop capabilities to design complex systems in the future. Further, this approach facilitates meeting challenging requirements of several ABET-based educational outcomes: technical as well as professional.

Keywords Multidisciplinary approach • Experiential learning • Engineering education • Product design • ABET outcome

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1 Introduction

This paper addresses the development of product design and realization (PDR) course offered as an open elective to pre-final year undergraduate students from engineering disciplines of Electrical and Mechanical Sciences. Product design is a complex process requiring a cross-functional team consisting of design engineers from different engineering disciplines. An experience of multidisciplinary nature usually presents itself during the professional career after graduation. To create such a learning experience at undergraduate level is a challenging task. Approaches to address the interdisciplinary challenge are presented in [1–3]. Attempts have been made at the post graduate level [4] with students from different disciplines. The Department of Electronics and Communication and Department of Automation and Robotics made an effort to design and deliver a course that allows the undergraduate student to experience the complete product design and realization process, working in a multidisciplinary environment.

The primary objectives of PDR course are: the student should be able to (1) design multidisciplinary projects culminating in a finished product, (2) engage in a systematic approach towards design, (3) develop a new product or improve an existing product. The students undergoing this course will also be well placed to explore the possibilities of entrepreneurial ventures, since they would be well equipped to handle all the aspects of product design and realization.

The scope of PDR in providing integrated learning experience in the undergraduate program is presented here and makes the following main contributions.

- The PDR course is designed to provide experience of ‘product’ using multidisciplinary teams at the undergraduate level.
- The course delivery uses innovative pedagogical approaches and they are
  - Processes of reverse engineering, user survey, need analysis, conceptual design and advanced tool learning are integrated into student training to provide a hands-on experience before the student initiates the process of PDR.
  - Sample case studies are facilitated by the course instructor to provide experiential learning.
  - Interactions with local entrepreneurs at their design and production facilities are organized to provide real exposure to the PDR process.
- Attainment of student outcomes, in particular outcome (e), assessed using continuous review process by an expert review committee comprised of faculty from the disciplines of both mechanical and electrical engineering sciences, is used for continuous improvement of the teaching–learning process.

In Sect. 2 the curriculum design process is illustrated that meets the course objectives. The pedagogical practices used in the course delivery and rubrics used for assessing student learning are discussed in detail. Section 3 illustrates the evaluation of the course and Sect. 4 lists the steps taken for continuous improvement. The conclusion is presented in Sect. 5.

2 Curriculum Design and Course Delivery

The process of curriculum design began by acknowledging the need for experience of product design at an undergraduate level, followed by interaction with prominent academicians and industry personnel. An evaluation of gaps in the skill sets of the graduate engineers was done, and an effort was made to address the issues. The conventional design flow using isolated disciplines/teams would result in increased product design life cycle thereby delaying the final product/prototype. It is important that in this course students become aware of the problems in optimizing the concurrent design processes involving coordination of the multidisciplinary technical functions of design to improve productivity. An innovative multidisciplinary design-to-realization approach is adopted in this course and student teams are required to design and build working prototypes for predefined products.

The entire course spanned 6 weeks during the summer vacation for the student. The first 2weeks comprised of:

- Interactive lecture sessions on product design process and basics of engineering design
- Active learning sessions on relevant topics of product design: Reverse engineering, User survey, Need analysis, Product planning, CAD tool usage, open-source tools
- Case studies incorporating idea generation, conceptual design, detailed design and prototype verification
- All assignments carried out as group activity involving teams made up of students from diverse engineering disciplines
- Industry visit to enable interaction with entrepreneurs and get acquainted with state-of-the-art industrial production equipments and product design and development
- Interactive sessions on 3-D printing for prototyping

The teams consisting of two students from electrical sciences and two students from mechanical sciences background were formed to ensure that each team has skill sets from both the disciplines. The products to be designed were carefully chosen to enhance the experiential learning process, rather than implementation of hi-tech products. The two products given for the student teams to choose from were:

1. Remote control for elderly people
2. Position sensitive Musical Toy

The institutions adopting the Outcome Based Education framework in engineering education are accredited worldwide as per ABET engineering criteria 2000 (EC 2000) [5] and as per new NBA accreditation in India [6]. Often, the capstone projects are used to evaluate student attainment of technical and professional outcomes [7]. Due to the integrative and multidisciplinary nature, the course helps the student to attain few of the challenging program outcomes specified by ABET. The programs can also use this course as a tollgate course to assess attainment of student outcomes by using proper assessment rubrics. The design process of a remote control for elderly people is presented here as a case study.

Table 1 Need analysis chart

Sl. no.	Requirement	Importance
1.	Provision to change channels, volume, power on and off	10
2.	Light weight	8
3.	LED indication for buttons	1
4.	Easily operated by both the hands	9

Table 2 Morphological chart

Functions	Option 1	Option 2	Option 3	Option 4
Accepting force	Press button	PC mouse button	Switch	
Processing signal	By standard IC	By micro controllers	By discrete components	
Holding the base and upper pieces	Adhesives	Screws	Snap fitting	Mechanical lock (notch, sliders)

2.1 Case Study of Remote Control for Elderly

2.1.1 Need Analysis

Need Analysis is the first phase of the course. The need is to design a product which can be used by elderly to handle different television operations with ease. The analysis of the constraints, like difficulty in handling small buttons, frequent fall of remote, trembling hands, confusion while handling more buttons, is documented and listed in the form of a need analysis table as shown in Table 1, which enables the designer to arrive at the primitive specifications of the product.

2.1.2 Product Planning and Market Analysis

The next phase is to estimate the time required for the product design and realization in the form of a Gantt chart highlighting the multiple tasks which could be either sequential or concurrent. Apart from user survey, the students conduct a market survey in the resident city and arrive at an estimate for the market consumption and approximate pricing.

2.1.3 Conceptual Design

After finalizing the specifications of the product to be designed, the student demonstrates the solution-neutral design. This involves listing of all the functions and subfunctions of the product in the form of a morphological chart. Table 2 shows a sample set of the concepts.

The morphological chart provides the student with an opportunity to select multiple options for each function implementation. The final concept selection is done

Fig. 1 PCB layout, CAD design and working prototype

Table 3 Evaluation rubrics sample set

Rubrics	
1.	Product planning
2.	Need analysis
3.	Identifying constraints, attributes, goals
4.	Team dynamics
5.	Morphological chart
6.	Detailed design
7.	Need mapping
8.	CAD modelling
9.	PCB design
10.	PCB implementation
11.	3-D printing of CAD model
12.	Demonstration

based on the needs and constraints analysis. This involves various trade-offs against size, cost, ease of use, availability of materials, simulation models and design complexity to name a few.

2.1.4 Detailed Design

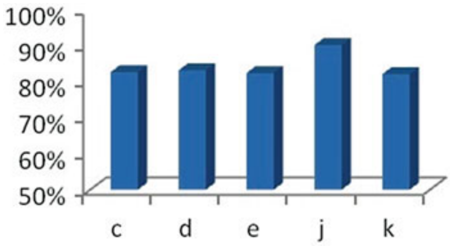
In this phase the student performs the functionality test using Proteus® simulation software after finalizing the electrical circuit schematic. The culmination of this phase is the design of PCB using Eagle® CAD tool and implementing it using the PCB prototyping machine.

The mechanical design process is carried out using Solid Works® software. The CAD model for the enclosure and all other functionalities provided by the mechanical subfunctions is shown in Fig. 1 along with the working prototype that has been realized. The unique feature of the product is that it adds the functionality of a remote control to a torch available in the market and uses the same battery source.

3 Evaluation

The evaluation is carried out based on a set of carefully designed rubrics specific to each area of design and realization process quantifying the degree of attainment of ABET outcomes (a–k). A sample set of rubrics is shown in Table 3.

Fig. 2 Attainment of ABET outcomes



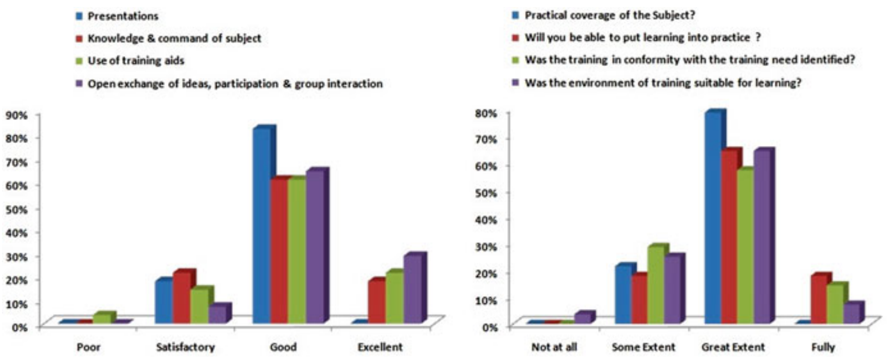


Fig. 3 Feedback analysis

The evaluation consists of two categories, namely Continuous Internal Assessment and Semester End Examination. The assessment of the PDR is carried out regularly twice a week, and teams' progress is evaluated and guided by an expert review committee comprising of faculty from both the disciplines of mechanical and electrical engineering sciences. The interactions are carried out with the intent of highlighting the issues in multidisciplinary design and team work. The experts provide the bigger picture of product design and realization without getting lost out in the technicalities of the design. The attainment of ABET outcomes is shown in Fig. 2, which indicates the attainment of both technical and professional outcomes adequately.

4 Continuous Improvement

Curriculum design is a continuous process and must evolve with the needs of the industry and skill levels of the students for a multidisciplinary course like PDR. The need to redesign the curriculum arises from many factors such as: Evolving global ecosystem of product design and development: Emerging technologies that enable multiple solutions to the problems encountered during product design and development: Redeployment of skills training in evolving regular courses in the undergraduate engineering curriculum: Overcoming the shortcomings of the previous courses based on the feedback from all the stakeholders.

The feedback analysis of the overall course experience is summarized in Fig. 3, which addresses the overall PDR course delivery. The analysis highlights the need to strengthen some aspects of course design and delivery.

5 Conclusions

An innovative multidisciplinary design-to-realization approach is adopted in this course and student teams build working prototypes for predefined products. This course brings a new perspective to the multidisciplinary approach to teaching product design. Introduction of project-based design experience at an early level provides students with an opportunity to develop capabilities to design complex systems in the future. An attempt is made to bridge the gap between the skill level of the graduates and the industry expectations, so that the students are industry ready. The outcome assessment meets the requirements of most of the ABET outcomes adequately and provides inputs for continuous improvement of the course. The future work is to share the experiences with the industry stakeholders and incorporate the suggestions into subsequent courses. At present the rubrics do not address the applicability as a tollgate course, however it can be extended as a tollgate course to assess attainment of student outcomes. Using this course as an early intervention for the students desiring to take up entrepreneurship opportunity is also explored.

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